PB81-209587

Development of a System to Protect Groundwater Threatened by Hazardous Spills on Land

Rexnord, Inc.
Milwaukee, WI

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

May 81

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/2-81-085
May 1981

PB81-209587

DEVELOPMENT OF A SYSTEM TO PROTECT GROUNDWATER THREATENED BY HAZARDOUS SPILLS ON LAND

by

K. R. Huibregtse
Rexnord Inc.
Milwaukee, Wisconsin 53214

K. H. Kastman
Soil Testing Services, Inc.
Northbrook, Illinois 60062

Contract No. 68-03-2508

Project Officer

Joseph Lafornara
Oil and Hazardous Materials Spills Branch
Municipal Environmental Research Laboratory--Cincinnati
Edison, New Jersey 08837

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

PRODUCT OF:
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.
EPA-600/2-81- 085

2.
ORD Report

3. RECIPIENT'S ACCESSION NO.
PB81 209587

4. TITLE AND SUBTITLE
DEVELOPMENT OF A SYSTEM TO PROTECT GROUNDWATER THREATENED BY HAZARDOUS SPILLS ON LAND

5. REPORT DATE
May 1981

6. PERFORMING ORGANIZATION CODE

7. AUTHOR(S)
K.R. Huibregtse; K.H. Kastman

8. PERFORMING ORGANIZATION REPORT NO.

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Rexnord, Inc.,
Milwaukee, Wisconsin 53214

10. PROGRAM ELEMENT NO.
AZB1B

11. CONTRACT/GRANT NO.
68-03-2508

12. SPONSORING AGENCY NAME AND ADDRESS
Municipal Environmental Research Laboratory - Cin., OH
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

13. TYPE OF REPORT AND PERIOD COVERED
Final

14. SPONSORING AGENCY CODE
EPA/600/14

15. SUPPLEMENTARY NOTES
Joseph Lafornara, Project Officer
Anthony Tafuri, Project Contact
(201) 321-6604

16. ABSTRACT

The purpose of this project was to establish an alternative approach to treatment of hazardous materials spills on land other than the frequently limited approach of excavation or flushing of the area with water. Direct grout injections enveloped spills to isolate them from groundwater and a mobile in-situ containment/treatment unit was constructed and mechanically tested. Grouting procedures were most applicable in gravel, sand and some silty soils. Treatability agents added to four soils during flow-through tests showed 99 percent detoxification.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Aquifer hydrogeology Protectors Water supply Hazardous materials Groundwater	Soils Developing	Hazardous materials Spills Land spills Water quality Pollution prevention	

18. DISTRIBUTION STATEMENT
Release to public

19. SECURITY CLASS *(This Report)*
Unclassified

20. SECURITY CLASS *(This page)*
Unclassified

21. NO. OF PAGES
143

22. PRICE

EPA Form 2220-1 (9-73)

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory--Cincinnati, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report describes the development, design and construction of a vehicle having the capability for containing and treating hazardous spills on land.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory
Cincinnati

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

ABSTRACT

Treatment of hazardous materials spills onto land that create threats to the quality of groundwater is frequently limited to excavation or flushing of the area with water. The purpose of this project was to establish an alternative approach to the solution of the problem. The objective was to develop, design and construct a vehicle capable of containing about a 40 m^3 (10,000 gal) hazardous spill on contaminated land and treating the polluted soils by oxidation/reduction, neutralization, precipitation or polymerization. The approach was to use direct injection of grout into the soil around the contaminated area to envelop the spill and isolate it from the groundwater, and detoxify the spill area by injection of treatment agents. Since information regarding this approach was minimal, both laboratory and pilot-scale tests were performed before the unit was designed, constructed and delivered to the U.S. EPA in Edison, New Jersey.

Treatability tests were performed on four soil types (gravel, sand, silt and clay) with three reaction types (oxidation/reduction, neutralization and precipitation). Flow-through tests were performed to simulate conditions in gravel, sand and silt while sealed tests were performed to approximate conditions in clay soils. Detoxification in flow-through tests exceeded 99 percent of the initial contaminant added and appeared to be the result of both displacement and chemical reaction. Sealed test detoxification efficiencies in clays ranged from 56.5 to 99.5 percent. Formation of insoluble products did not adversely affect detoxification.

A simultaneous evaluation of grout formulations and injection devices indicated that grouting was most applicable in gravel, sand and some silty soils. The direct driving of heavy duty pipe is recommended to minimize short-circuiting and to lower costs. Two types of grout (bentonite/cement and sodium silicate) were selected as most applicable.

Pilot-scale tests were performed, which verified the results of treatability tests, evaluated grout injection procedures and identified potential design problems.

A mobile in-situ containment/treatment unit was designed, constructed and mechanically tested before it was delivered to EPA. Major components located on a 13.1 m (43 ft) drop deck trailer include: a diesel electric generator, an air compressor, two 2.46 m^3 (650 gal) lined tanks with mixers, four 0 to 30 lpm (0 to 8 gpm) progressive cavity pumps, four 0 to 76 lpm (0 to 20 gpm) air diaphragm pumps, a control panel, flow controls and a solids feed conveyor. Decision guidelines for unit mobilization and an operations and maintenance manual were provided with the containment treatment unit.

This report was submitted in fulfillment of Contract No. 68-03-2508 by Rexnord Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period 12/76 to 4/79, and work was completed as of 4/79.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA
OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

CONTENTS

Foreword...iii
Abstract.. iv
Figures... vi
Tables...vii
Acknowledgment..viii

1. Introduction... 1
    - Project Objective.................................... 1
    - Project Approach..................................... 1
2. Conclusions.. 4
3. Recommendations.. 7
4. Treatability Studies..................................... 9
    - General.. 9
    - Soil Selection....................................... 9
    - Chemical Selection................................... 14
    - Testing.. 20
    - Analytical Procedures................................ 25
    - Results and Discussion............................... 27
    - Applicability of Treatability Test Results to Larger Scale System Use.......................... 40
5. Grout as a Spill Containment Mechanism................... 46
    - Grout Containment Techniques......................... 46
    - Grout Selection...................................... 47
    - Subsurface Conditions Requiring Grouting............. 49
    - Grout Injection Devices.............................. 49
    - Project Applicability of Grouting.................... 51
6. Pilot Studies.. 52
    - Detoxification Testing............................... 52
    - Grouting Tests....................................... 60
    - Applicability to System Use.......................... 61
7. Prototype Design, Construction and Testing............... 63
    - System Design.. 63
    - Construction and Testing............................. 80
8. Special Considerations for Implementation................ 82
    - Introduction... 82
    - Spill Scenario....................................... 83
    - Chemical Treatability................................ 84
    - System Limitations................................... 88
    - User's Decision Guides............................... 91
    - Special Considerations for Detoxification Equipment.................................. 100

References... 105
Appendix... 107

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

FIGURES

Number		Page
1	Schematic of operating approach for spill containment and treatment	2
2	Rate of styrene polymerization under favorable conditions	21
3	Schematic of test column	26
4	Flow-through test procedure and equations for calculation of results	32
5	Generalized concentration trends in flow-through testing	34
6	Sealed test procedure and equations for calculation of results	37
7	Average results of contaminant migration during sealed tests	39
8	Copper contaminant concentrations with depth in clay for various bulk densities and contaminant loading	41
9	Contaminant entrainment versus soil particle size	44
10	Relationships between entrained contaminant reacted and flushed versus soil particle size	45
11	Schematic of grout flowing through soil	47
12	Sealed pilot testing apparata	53
13	Schematic of flow-through testing layout	54
14	Flow-through pilot test box	56
15	Process and instrumentation diagram of prototype unit	64
16	Schematic layout of prototype unit	77
17	Pictures of in-situ containment/treatment unit	78
18	Two views of the operator's area	79
19	Plan view of grouting set-up and spill area	85
20	Overview of decision making procedures	93
21	Decision guide for advance team	97

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

TABLES

Number Page

1 Properties of Selected Soils 12

2 Soil Chemical Characteristics 11

3 Redox Contaminant Rankings (1) 15

4 Neutralization Contaminant Rankings (1) 17

5 Polymerization Contaminant Rankings (1) 18

6 Summary of Chemical Systems Evaluated in the Program 22

7 Summary of Laboratory Test Variables 24

8 Summary of Treatability Study Results for Flow-Through Testing 30

9 Tests for Internal Soil Variable Significance for Flow-Through Testing 31

10 Summary of Sealed Test Results 38

11 Summary of Sealed Pilot Test Results 57

12 Summary of Flow-Through Pilot Test Results 58

13 System Specifications and Justification 66

14 System Components Advantages/Disadvantages/Competitive Prices 71

15 Major Components Procured for System 75

16 Summary of Time and Material Requirements for a Hypothetical Spill Situation 86

ACKNOWLEDGMENTS

The authors gratefully acknowledge the assistance of many individuals in the development of the in-situ treatment system and in the preparation of this report. Special thanks are extended to the Project Officer, Dr. Joseph Lafornara, for his help and guidance throughout the project. Other staff members of the Oil and Hazardous Materials Spills Branch of the Industrial Environmental Research Laboratory, N.J. in Edison also provided valuable assistance. In particular, thanks are extended to Mr. Frank Freestone.

The development of the equipment was a combined effort of many people at Soil Testing Services (STS) and the Rexnord Environmental Research Center (ERC). Mr. Mel Teske worked long hours on the treatability evaluations and Mr. Tom Woida executed most of the pilot tests. Their hard work is gratefully acknowledged. Mr. Dave Belongia of STS-Wisconsin provided valuable input on all phases of the project. Design and construction were mainly handled by Mr. Gary Rollinger of ERC; his innovative ideas and hard work were greatly appreciated. Mr. Bill Kreutzberger and Mr. Joe Kuderski contributed much time and effort to the final report and slide/picture compilation. Without their help, the work would have been much more difficult. Finally, the authors would like to thank all other staff members at STS and ERC who were involved in the project and contributed to its success.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

SECTION 1

INTRODUCTION

Accidental spills of hazardous chemicals are potentially one of the most severe threats to the environment. These spills can occur anywhere, contaminating air, water and/or soil. The type and volume of chemical spilled and the time of occurrence cannot be predicted, thus treatment response is extremely difficult. The state-of-the-art for spill cleanup is more advanced with respect to spills into bodies of water. Land spills that threaten groundwater can be equally serious and will also require effective actions to safeguard the environment.

8-1/2"

The present technology of land spill cleanup has consisted mainly of excavation, flushing the contaminated area with water, or containment by natural barriers created by the presence of soils with low permeability. Because these techniques are not always appropriate, the Environmental Protection Agency (EPA) funded a project under Contract No. 68-03-2508 to develop a mobile system that is capable of protecting groundwater threatened by hazardous materials spills by detoxifying many contaminated soils in place (in-situ).

PROJECT OBJECTIVE

The project goal was to develop, design and construct a vehicle capable of containing about a 40 m^3 (10,000 gal) hazardous spill on land and treating the polluted soils by oxidation/reduction, neutralization, precipitation or polymerization. The general approach consisted of direct injection of grout into the soil around the contaminated area to envelop the spill and isolate it from the groundwater, and detoxification within the spill area by injection of treatment agents. Figure 1 presents a schematic diagram of the general response technique.

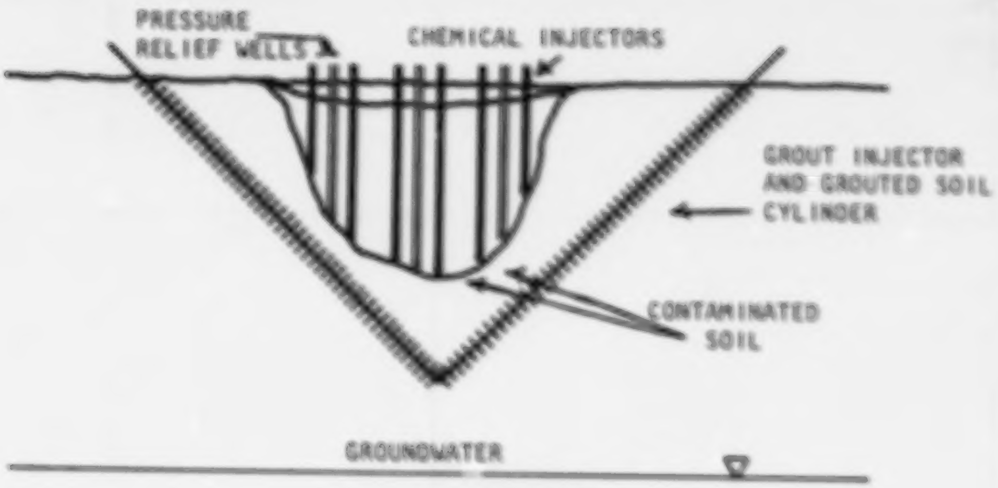
It was recognized initially that grouting and treatment by injection could be applied separately, depending upon site specific requirements. Similarly, the basic limitations of any injection procedures to more permeable soils were known. The objectives of this project required a more precise definition of the potential applicability and limitations of the conceptual approach.

PROJECT APPROACH

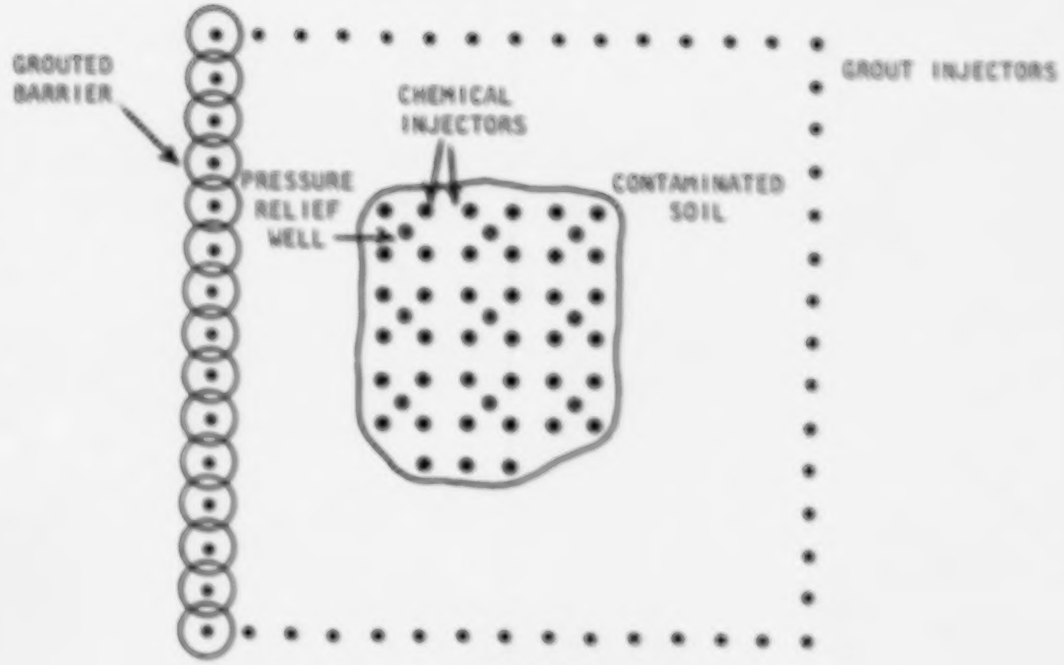
Information on soil/chemical systems related to in-situ treatment was minimal so both laboratory and pilot scale tests were necessary before

BOTTOM OF IMAGE AREA (OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS)
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-78)


PRESSURE RELIEF WELLS
CHEMICAL INJECTORS
GROUT INJECTOR AND GROUTED SOIL CYLINDER
CONTAMINATED SOIL
GROUNDWATER

CROSS SECTIONAL VIEW


GROUTED BARRIER
CHEMICAL INJECTORS
GROUT INJECTORS
PRESSURE RELIEF WELL
CONTAMINATED SOIL

PLAN VIEW

Figure 1. Schematic of operating approach for spill containment and treatment.

the *in-situ* containment treatment system could be developed. The treatability tests that were performed on a laboratory scale demonstrated the efficiency of chemical detoxification within a soil system. A separate evaluation of grout for use in spill containment required a review of grout types and injection devices before the laboratory evaluation. Pilot tests were then performed to provide larger scale confirmation of the treatability test results and additional information on system design and construction. After the unit was constructed, limited mechanical testing was performed.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

SECTION 2

CONCLUSIONS

1. Laboratory-scale treatability tests performed on four soil types (gravel, sand, silt and clay) and three chemical reaction systems (oxidation/reduction, neutralization and precipitation) showed that in-place detoxification removed up to 100 percent of the contaminating chemical.

2. Two types of tests were conducted: flow-through tests that represented detoxification in gravel, sand and silt; and sealed tests that were indicative of decontamination in clays. Total detoxification for flow-through testing exceeded 99 percent of the contaminant added for all soils and chemicals tested. The detoxification effectiveness of sealed tests in clays ranged from 56.5 to 99.5 percent.

3. Total detoxification for flow-through testing consisted of contaminant displacement and chemical reaction. A clean water rinse was needed to displace excess reactant from the soil surfaces.

4. Reactions that result in the formation of either soluble or insoluble products can be used for in-situ detoxification.

5. The percentage of contaminant remaining in the soil (entrained) following treatment depends upon the soil type. Gravels entrain the least amount of contaminant as a percentage of void volume available while clays retain the most.

6. The migration rate of contaminants in the clay soil was extremely low. Most material remained in the top 1 to 3 cm after 24 hours.

7. Formation of a grout envelope by driving closely spaced injectors on an angle around the edge of the spill was chosen as the best containment method in a spill response situation where grouting procedures are appropriate. Currently available grout types most applicable were bentonite/cement, bentonite and sodium silicate formulations. Grout depths using driven injectors are generally limited to 7.6 m to 9.2 m (25 to 30 ft) vertical distance.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

8. Containment, using grout, will be most effective for a well graded sand and gravel mixture, a fine sand and possibly sandy silts. Grout types used in a spill situation must be compatible with soil types and contaminant properties. Fine grained silts and clays are not amenable to grouting. This basic limitation must be recognized in order to use the equipment most effectively.

9. Various grout injector rods are available. The use of Schedule 80 black steel pipe allows initial cost savings and can be easily replaced from local suppliers. The length of service of any injector will be reduced as a result of the corrosive effect of treatment agents and contaminants.

10. Pilot tests to evaluate redox and precipitation reactions were performed on sand and clay soils. The results indicated that detoxification in sand ranged from 71 to 100 percent and from 57.3 to 99.9 percent in clay.

11. Pilot tests also indicated: 1) the importance of direct driving injectors to reduce short-circuiting, 2) the necessity for a wet well equipped with a self priming pump for liquid removal and 3) the need for pumps capable of handling pressures up to 552 kN/m^2 (80 psig).

12. Chemical grout gel times in the field were temperature dependent and shorter than those predicted in the laboratory. Particulate grouts were best regulated by back pressure, while chemical grouts could be regulated by measuring the volume pumped into the soil.

13. Mechanical testing indicated that the unit was capable of pumping simulated grout into a sandy soil. Most of the in-situ containment treatment system is located on a 13.1 m (43 ft) drop deck trailer. The major components include: two 2.46 m^3 (650 gal) tanks with mixers, four progressive cavity pumps, four air diaphragm pumps, a diesel-electric generator, a compressor, a control panel, flow measurement gages and a solids feed conveyor. Auxiliary equipment includes a soil auger, hosing, injector driving scaffolding, injectors, an air hammer and a hydraulic retractor.

14. Operation of the unit in the batch feed mode will provide flexibility in handling a wide variety of chemicals and grouts. The size of the spill or contaminated area that can be handled is limited mainly by the time and raw material constraints, not by the system construction.

15. Treatment of all chemical compounds spilled onto soils is not possible. Techniques for detoxification include rinsing with dilute acids, bases, redox agents, precipitating compounds, and pure water. A prerinse may be desirable to remove soluble constituents for surface treatment. A post reactant rinse is always required when it is felt that a vertical barrier exists or

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

has been attained by grouting. Rinsing or flushing may not be desirable if direct migration to the underlying aquifer is possible.

16. Containment by grouting and chemical treatment by injection are processes which can be applied separately depending upon the specific situation. Soil permeabilities can limit the usefulness of either technique. Also, the effects of hydraulic forcing of contaminant or reactant into uncontaminated areas must be considered when selecting the treatment process and operation.

17. Grout selection must be correlated with soil type and class of chemical spilled. The integrity of grout barriers contacted with different chemicals requires further testing.

18. Physical and chemical properties of soil can limit the use of in-place containment or treatment. Small grain sizes or the presence of clay lenses in the spill area may preclude grouting. A shallow or fast flowing ground water layer may also make in-situ containment or treatment difficult. Soil chemical characteristics, such as buffering, adsorption, reduction and cation exchange capacity and mineral content, can affect the amount of chemicals needed for detoxification as well as the effectiveness of reaction.

19. A decision guide approach that involves the dispatch of an advance team to evaluate site specific conditions is presented. Information obtained from on-site testing can be used to estimate treatment effectiveness and material requirements so that an authorized coordinator can determine if mobilization of the in-situ containment/treatment unit is warranted.

20. Because of its flexible design, the in-situ containment/treatment system can be adapted to uses other than spill response. With only minor modifications to the unit, application to leaking landfills or hazardous waste disposal sites is particularly promising.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

SECTION 3

RECOMMENDATIONS

1. Further laboratory scale evaluations of soil/chemical treatability should be performed. Soil types that may interfere with reactions and mixtures of hazardous chemicals should be tested to establish effectiveness of detoxification in more complex circumstances.

2. Chemical, soil and grout interactions should be tested to allow development of specific guidelines. Similarly, a short-term testing procedure using actual contaminated soil should be developed in order to allow determination of grout/chemical compatibility.

3. A decision making procedure should be developed that allows a determination of the feasibility for using the in-situ equipment quickly and effectively. This procedure should be comprised of a team that includes an authorized coordinator, a trained on-site observer and a specially trained and equipped advance team.

4. The advance team that is sent to a spill site should immediately evaluate on-site circumstances and determine if in-situ containment or treatment is feasible. The team should consist of at least two people with soil and chemical treatability expertise. Field equipment should include soil sampling equipment and apparatus for soil and chemical analyses. A guide for anticipated soil conditions at various locations would be useful for making rapid decisions.

5. Experience gained during field operation should be incorporated into a series of guidelines that will help to establish when the in-situ containment treatment equipment should be mobilized.

6. Grout types to permanently install faster grout envelope formation should be evaluated. This evaluation could include other new market grouts or grout barrier formation methods such as a jet cutting grout wall.

7. How the equipment responds to hazardous materials in non-spill situations should be evaluated. Existing but abandoned industrial waste disposal sites or leaky landfills should be considered for grouting and in-place detoxification.

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

8. The equipment should be periodically re-evaluated in order to determine its usefulness and to consider modifications so that equipment can be upgraded to the current state-of-the-art for grout injection and chemical treatability.

6 1/2"
9 1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

SECTION 4

TREATABILITY STUDIES

GENERAL

The first step of the project involved an evaluation of the effectiveness of in-situ treatment techniques for soil detoxification. Little previous information was available on this subject, so laboratory scale treatability tests were required. Extensive testing was performed on four soil types and three chemical systems. The variables evaluated included the contact time, the soil conditions and the amount of contaminating chemical in the soil void spaces. A special test apparatus, shown and described later, in this report, was developed and the test results were evaluated in order to determine the efficiency of the in-place detoxification approach.

SOIL SELECTION

Soils that may typically be found at the upper ground surface exist in a wide range of particle size gradations and in various conditions of moisture content and unit weight. Variations in soil formation and deposition can result in complex combinations of particle size, as well as variable natural chemical constituents and pH levels. The general approach for determining soil types for treatability testing was to select uniformly graded soils comprised of particles that had low levels of potential reactivity with detoxification chemicals.

Four soils, each representing one of the major particle size classes, were selected. The soils were clay, silt, sand and gravel. Each soil type was chosen such that its gradation would fall almost entirely within the commonly defined particle size range for that soil category. The removal of fine grained (clay) particle sizes (smaller than 0.074 mm, 0.003 in.) from the coarser grained samples was important. This was done in order to prevent properties (such as permeability) of the sand or the coarser soils from being controlled by the presence of a small percentage of clay in the sample. In addition, each of the soil samples was selected to be as chemically neutral as possible so that the soil particles themselves would not enter into the various detoxification reactions investigated.

Before beginning the treatability evaluations, each soil sample was tested to define basic physical and chemical properties. The source of samples and the general properties and results of the laboratory testing program are discussed below.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE
6-1/2"

Soil Types

Clay--

The clay selected was a kaolin clay designated as T-7 clay by the Kraft Chemical Company of Chicago, Illinois. This clay is mined and processed in Georgia and is commonly referred to as "Georgia kaolin". It is mainly comprised of the clay mineral kaolinite. Kaolinite has the lowest attenuation capacity of the three major clay minerals: montmorillonite, illite, and kaolinite. Kaolin clay was selected in order to minimize the interaction between the clay and the waste contaminant and/or detoxification reactant.

Silt--

A ground silica sand, known commercially as a No. 290 silica flour, was the silt selected for this study. This uniformly graded material was obtained from the Ottowa Silica Sand Company. Because it has a silica oxide sand base, there is little potential for reaction or interaction with most detoxification chemicals.

Sand--

The sand utilized in the test program was an equal blend of two gradations of silica sand, designated as Flintshot and No. 1 Federal fine. A second sample of silica sand, slightly finer in gradation than the first blend, but similar in all other respects, was introduced to the test program at a later date when the initial gradations were no longer available from the producer. Both samples had uniform subangular particle shapes. As in the case of the silt, the silica oxide sand is generally inert and should not participate in the detoxification reactions.

Gravel--

The gravel selected for this project was derived from the crushing of granite bedrock, which is known commercially as "traprock". The particle shapes were highly angular and the gradation was almost entirely gravel-sized. As a result of its granite origin, traprock is basically inert.

Classification and Index Tests

After selecting the four representative soil samples, general classification and index property tests were performed. The tests were intended to define the nature of the soils and their potential to exist in-situ at varying density and moisture conditions. Because specific definition was important it was believed that these variables have a significant effect upon the amount of contaminant that can be contained within the soil structure.

Permeability tests were also performed. The permeability indicates the rate at which a fluid will flow through the soil structure. The possible range in permeability through soil is extremely wide, ranging nearly nine orders of magnitude, from terms defined in centimeters per year up to meters per day. Permeability is a key factor in understanding the potential for contaminant and reactant flow through soils.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

Two types of permeability tests were performed, a falling head test and a constant head test. The two tests were selected to model two significant stages of this project. The falling head test is analogous to the contaminant spill seeping into the soil, while the constant head test is similar to the injection of a grout curtain around the waste spill, which is performed under relatively constant pressure.

All tests were performed according to ASTM specifications, where they were appropriate. The results of soil classification, index and permeability tests are summarized in Table 1.

Soil Chemical Tests

The four soil samples were also tested to determine their cation exchange capacity (CEC), pH and conductivity. This was done in order to ascertain the potential reactivity of the soils. The soils selected were found to be relatively inert, thereby minimizing the potential for reactions between the soil particles and the detoxification chemicals or grout. All of the soils were found to be slightly basic with the exception of the kaolin clay, which was mildly acidic.

The cation exchange capacity is an indication of the soil's ability to absorb contaminant materials. A high ion exchange capacity indicates a high ability of the soil to hold a contaminant within its structure and would indicate potential treatment difficulties. Typical cation exchange capacities for natural clay soils range from 5 to 30 milliequivalents or more per 100 grams. The clay selected for this study had a cation exchange capacity of 2 and was quite inert relative to typical clays. The pH of the soils was within a naturally occurring range. Also, the specific conductance test results indicated low potentials for chemical soil interactions. Chemical test results are presented in Table 2.

TABLE 2. SOIL CHEMICAL CHARACTERISTICS

Soil type	Cation exchange capacity (CEC), me/100 g	pH	Specific conductance, µmhos/cm
Gravel	0.13	9.38	45
Sand	0.04	8.83	70
Silt	0.10	8.41	100
Clay	1.70	5.13	20

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

TABLE 1. PROPERTIES OF SELECTED SOILS

Property type	Gravel	Sand	Silt	Clay
Material used	Trap rock	Silica sand	Silica powder	Kaolin
Specific gravity, g/cm³	3.00	2.65	2.64	2.57
Maximum density, g/cm³ (modified proctor)	1.83	1.72	1.71	1.64
Optimum water content, %	1.1	11.0	15.0	20.4
Void ratio, e	0.639	0.541	0.544	0.567
Porosity, η	0.390	0.351	0.352	0.362
Permeability, cm/sec				
Constant head	1.03×10^{-2}	8.9×10^{-4}		
Falling head			4.0×10^{-6}	9.8×10^{-9}
Percent passing, %				
3/4" Sieve, 19.1 mm	98.0	100.0	100.0	100.0
No. 4, 4.76 mm	17.5	100.0	100.0	100.0
No. 40, 0.420 mm	0.0	52.0	100.0	100.0
No. 200, 0.074 mm	0.0	0.0	87.5	98.0

in. = mm x 0.039

EPA-287 (Cin.)
(4-76)

Summary of Soil Properties

In summary, the characterization of the four soil samples included the following tests:

1. Grain size analyses
2. Specific gravity
3. Maximum and minimum densities
4. Density vs. water content relationships
5. Soil plasticity by Atterberg limit tests
6. Permeability by falling head tests
7. Permeability by constant head tests
8. Cation exchange capacity
9. pH
10. Specific conductance.

The reference for the test methods used for the above listed soil analyses are presented below.

Test number	Reference
1	Sample preparation - ASTM* D421-58 Wet sieve procedure - ASTM D1140-54 Hydrometer procedure - ASTM D422-63
2	ASTM D854-58
3	ASTM D2049-69
4	ASTM D698 (standard) ASTM D1557 (modified)
5	ASTM D423-66 ASTM D424-59
6	Method developed by STS**(M. Silver, et.al.)
7	Method developed by STS (M. Silver, et.al.)
8	Methods of Soil Analysis, American Society of Agronomy, Book No. 9, Part 2, 1965, p. 891.
9	Ibid, p. 920
10	Ibid, p. 936

* American Society for Testing and Materials.
** Soil Testing Services, Inc., Northbrook, IL.

The grain size analyses, specific gravity, maximum and minimum density and density versus water content tests were useful in determining the various bulk density and void ratio conditions possible for each soil type.

The Atterberg Limit tests helped to define the soil's plasticity, workability and similarity to other soils. The permeability tests were used in determining the flow characteristics of fluids through the soils. The cation exchange capacity, pH and conductivity tests served to define the soil's general chemical reactivity.

CHEMICAL SELECTION

Although many different hazardous chemicals may be spilled, four representative chemical reaction systems were studied during this investigation. The four basic reactions that appeared to be possible mechanisms for in-place detoxification were: 1) oxidation/reduction, 2) precipitation, 3) neutralization and 4) polymerization.

To test these reactions, contaminant/reactant pairs representative of the type of detoxification that was to occur were selected for treatability studies. The contaminant choices were made based on the following criteria:

1. High risk of spillage (1)
2. Common use of the chemicals (1)
3. Directness of the chemical reaction to a simple kinetically favorable reaction system.

The choice of the treatment agent or reactant was based on:

1. Hazards of the treatment material
2. Quantity available on short notice
3. Difficulties of handling (safety, ease of handling)
4. Minimum amount required for detoxification.

Choices of concentrations for test contaminants were based on common shipping conditions, whenever possible. When a solid was involved, the solubility was used to determine the liquid concentration of the spilled material, assuming that rainfall or groundwater would provide the carrier medium. Reactant concentrations were determined by reaction conditions. It was desirable to eliminate excessive rates and heats of reaction in the soil. Although mixing tests indicated that a relatively concentrated reactant was feasible, use of such a reactant was not always possible in field situations because of unfavorable reaction requirements, such as pH constraints. Preliminary column tests were necessary to establish the acceptable reactant concentrations.

Oxidation/Reduction Reactions

Oxidation/reduction (redox) reactions are common reactions that detoxify hazardous materials through the transfer of electrons from a donor (reducer) to a receiver (oxidizer). The products formed are generally soluble and the reaction occurs relatively quickly and is usually exothermic. However, redox reactions are often pH specific, which reduces their applicability in a field situation. Many hazardous chemicals including chlorine solution, sodium bisulfite and hydrogen cyanide may be treated using redox reactions. Cyanide hydroxylamine, methyl mercaptan, sodium sulfite, sodium hydrosulfide, chromate and arsenic compounds may also be treated using these reactions.

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTIONS HERE

Evaluation of possible contaminants was completed by using lists of common chemicals that were not limited by pH constraints. The rankings with regard to quantity shipped and potential for spillage for selected redox contaminants are presented in Table 3.

TABLE 3. REDOX CONTAMINANT RANKINGS (1)

Chemical	Quantity shipped*	Risk of spillage*
Chlorine	44	12
Sodium hypochlorite	144	53
Calcium hypochlorite	164	54
Sodium sulfide	110	30

*Relative position of 257 chemicals investigated.

All the chlorine compounds will form the hypochlorite ion and, because this chemical is commonly used in homes and industry, a sodium hypochlorite solution was chosen to represent a redox contaminant. The concentration tested was established by the shipping strength of industrial hypochlorite, 12.5 to 15 percent by weight as sodium hypochlorite.

Three reducing agents were considered as the treatment agent to detoxify hypochlorite spills: sodium metabisulfite, sodium sulfite, and sodium bisulfite. Tests were performed to determine which reactant required the least volume to neutralize a given amount of hypochlorite. Sodium bisulfite was most favorable. The reactant concentrations of the treatment solution were determined by the amount of heat generated during the reaction. Although it was desirable to minimize volumes handled, high concentrations resulted in excessive heat build-up (66°C, 150°F). A concentration of 75 mg sulfate/mg hypochlorite allowed a more controlled reaction and a lower heat accumulation.

Precipitation Reactions

Precipitation reactions detoxify pollutants by reacting these materials to form relatively insoluble products with less potential for migration to the groundwater. Precipitation can be effective in insolubilizing various heavy metal compounds including iron, zinc and copper salts; some forms of arsenic, chromium and mercury compounds; and some organic fatty acids. The major problems associated with precipitation are:

1. The potential for resolubilization.
2. The need for careful pH control in some treatments.
3. The potential problems associated with forming an insoluble ring of precipitate that further isolates the reactant and contaminant.

BEGIN LAST LINE OF TEXT
OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
6-1/2"
3/8"
PAGE NUMBER

EPA-287 (Cin.)
(4-76)

Careful choice of reactant should minimize resolubilization and control problems. The major obstacle anticipated was formation of an insoluble product that could block passage of the reactant, stop any natural migration and eliminate additional detoxification.

In the case of precipitation, it was desirable to choose a reactant before the contaminant choice was made because of its relative advantages. Common reactants included hydroxides, oxides, sulfides and sulfates. Choice of reactants was based upon widespread applicability of the reaction type, pH control, secondary pollution and relative insolubility. Some preliminary testing had been performed on sulfide treatment of metal spills in water (2). The results from this evaluation indicated widespread applicability of this technique because of low rates of resolubilization and occurrence of the reaction at a neutral or slightly alkaline pH. Addition of sodium hydroxide to the solution kept the pH at a level that minimized the formation of hydrogen sulfide gas. The recommended concentrations of one molar sodium sulfide with one tenth molar sodium hydroxide were chosen for the treatability testing (2).

Various metal salts were considered as contaminants. The sulfide was shown to react effectively with zinc, cadmium and copper; however, zinc reactions left a high residual of unreacted sulfide. Copper required smaller amounts of sulfide addition, was quite commonly used, and had a relatively high risk of spillage. Therefore, copper sulfate ($CuSO_4$) was chosen to be the tested contaminant. Copper sulfate is usually shipped as a solid, so a liquid concentration level had to be chosen for testing. A concentration near the solubility at ambient conditions was determined by laboratory testing to be 9.86 g/100 ml. This concentration was used for all further testing.

Neutralization Reactions

Neutralization reactions provide their own pH control and proceed quickly under many different conditions. In addition, the only by-products of neutralization reactions are water and the associated anions and cations. In most cases, dilution of the ions by naturally present water, reactant dilution water and reaction water will reduce harmful concentrations. Neutralization can be used to detoxify a wide variety of compounds including sulfuric acid, sodium hydroxide, potassium hydroxide, hydrofluoric acid, benzoyl chloride, chlorosulfonic acid and sulfur monochloride. However, because of viscosity differences, it may be difficult to force mixing in the soil systems. Concentrated pockets of reactant and contaminants could stagnate in the soil system with little natural migration. This situation will adversely affect the usefulness of neutralization as a detoxification technique.

In order to test neutralization it was desirable to choose a straightforward acid/base system. Several acids including sulfuric, hydrochloric and nitric were considered (See Table 4).

TABLE 4. NEUTRALIZATION CONTAMINANT RANKINGS (1)

	Quantity shipped*	Risk of spillage*
Sulfuric acid	1	27
Hydrochloric acid	24	40
Hydrofluoric acid	63	66
Nitric acid	7	21

*Relative position of 257 chemicals investigated.

There is 4.6 times as much sulfuric acid shipped as nitric, because sulfuric acid is used in a wider variety of large-and small-scale industrial processes. Therefore, sulfuric acid was selected as the contaminant for study in neutralization testing.

Generally, sulfuric acid is shipped in bottles, carboys, drums and by tank car and tank truck. The most common concentration is 66° Baume or 93.2 percent H_2SO_4 and 36N strength acid. A less frequent concentration is 60° Baume (77.7 percent H_2SO_4). A sulfuric acid concentration of 36N was chosen.

Three commonly available chemicals may be used to neutralize sulfuric acid: sodium hydroxide, calcium hydroxide and calcium carbonate. Calcium carbonate was eliminated because of its tendency to form gases during the reaction. Preliminary tests with calcium hydroxide indicated that the precipitate blocked the soil voids, causing heat buildup at the interface, and decreased permeability. Therefore, sodium hydroxide was the reactant choice. The concentration of the reactant was established by minimizing excessive heat accumulation in testing. A one normal solution of NaOH was found to be acceptable.

Polymerization Reaction Study

Polymerization reactions are the production of long chain molecules by joining together a series of individual monomers. Two types of polymerization reactions have been defined:

1. Stepwise (condensation) polymerization
2. Addition or chain (radical, ionic or coordination) polymerization (3).

Because it is necessary to remove reaction products, often water, from the reaction system during stepwise polymerization, this type of reaction was not considered feasible for in-situ utilization. Since no by-products are obtained when addition polymerization is practiced, and a high weight polymer is formed at once with a reaction time that affects the yield

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

but not the molecular weight, further consideration was given only to addition or chain polymerization.

Chain Polymerization--
Chain reactions produce long chain or addition polymers and can be catalyzed through three mechanisms: radical initiation, ionic (anionic or cationic) initiation or coordination with a metallic catalyst. An investigation of the various types of chain or addition polymerization indicated that use of free radical polymerization was most broadly applicable. A majority of monomers can be catalyzed by using free radical mechanisms; such processes have less potential interferences (which must be overcome by additional initiator presence).

Choice of Monomer--
Once the reaction mechanism was established, the type of monomer to be used for testing was chosen. Eight common hazardous monomers could potentially be catalyzed using chain polymerization that was free radical initiated. Ranking of the quantity of monomers shipped and their spillage risks are presented in Table 5.

TABLE 5. POLYMERIZATION CONTAMINANT RANKINGS (1)

	Quantity shipped*	Risk of spillage*
Styrene	8	10
Acrylonitrile	53	4
Vinyl acetate	58	112
Methyl methacrylate	80	135
Isoprene	130	15

*Relative position of 257 chemicals investigated.

No information was available for acrolein, allyl alcohol and allyl chloride. Additional investigation into the monomers styrene and acrylonitrile indicated that the styrene monomer was readily polymerized under a variety of conditions and was shipped with only low concentrations of inhibitor (12 to 50 mg/l). Therefore, styrene was chosen as the monomer to be studied.

Reaction Method and Initiator Choices--
Styrene can be polymerized in many different ways; however, only two methods involve a water phase (4, 5). The reaction types that could be applied in the field are emulsion and suspension polymerization. Suspension polymerization requires the use of a styrene soluble initiator and emulsion polymerization involves a water soluble initiator. Evaluation of initiator materials showed that these chemicals were extremely hazardous themselves, often exhibiting explosive properties. Two

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-78)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

emulsion polymerization initiators, potassium persulfate and persulfuric acid, appeared to be most practical for field use; however, the reaction temperatures were higher than ambient (30 to 80°C, 86 to 176°F). It is possible to form free radicals through a redox reaction with iron or sodium thiosulfate, but this is not a common approach in industrial applications with styrene.

Determination of Reaction Conditions--
As a result of the potentially dangerous nature of the toxic by-products in uncontrolled polymerization reactions, we were careful to find a well-defined approach to testing the polymerization mechanism. A basic "recipe" for emulsion polymerization was found (6):

180 parts water
100 parts styrene
5 parts fatty acid soap (Ivory)
0.5 parts potassium persulfate
Heat to 50-60°C (122 - 140°F)

6-1/2"

Special reaction vessels were required because the initial reaction was to be performed under a nitrogen atmosphere in order to prevent oxygen contamination. The specific nature of polymerization reactions indicated the potential of several major problems in field application. One problem was temperature, because most reactions are carried out at higher than ambient temperatures to allow initiator activation and then continuation of the reaction. This problem may be overcome through the use of a redox initiator, however, little information was available on this technique.

An additional problem was the presence of oxygen which can act as an inhibitor initially and as an air initiator at later stages in the reaction (7). Since it is not possible to completely eliminate oxygen in a field situation, the air could cause severe problems for in-situ polymerization effectiveness. Another potential problem was contact between the initiator and the monomer being reacted. Soil particles may exert an initiator "demand" that will lower the amount of initiator contacting the monomer. This interference or demand could significantly reduce or stagnate the rate of reaction. Finally, effective mixing between the initiator and monomer within the solid may be extremely difficult.

Laboratory Testing--
Because there were many potential problems that could impact polymerization reactions adversely, preliminary tests were performed before beginning the soil/chemical evaluations. Tests were performed under conditions that made polymerization increasingly unfavorable. If monomer conversions were less than 50 percent in 48 hours, further testing was eliminated. First, tests were done to determine if polymerization was feasible under ambient conditions.

The first test involved immersing the reaction vessel in a water bath at 50 to 60°C (122 to 140°F). Sodium hydroxide was used to strip the

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

inhibitor from the monomer before it was added to the mixture of water, emulsifier and initiator. Samples were removed every half hour, washed with methanol and weighed. The results are plotted in Figure 2. A second test was then performed, keeping all the variables and the procedures the same, except lowering the temperature to 20°C (68°F). At 20°C, no measurable polymerization occurred over 24 hours.

These results indicated that another method of polymer initiation would be necessary for in-situ treatment. No information regarding other techniques for styrene initiation could be found. It was concluded that, under most circumstances, polymerization was not a viable method for treatment of organic spills in place. This decision was based on:

1. The difficulty in initiating reactions at ambient conditions
2. The unpredictable reaction mechanisms in a field operation
3. The dangers associated with handling initiators
4. The limited usefulness of polymerization in general
5. The presence of polymerization inhibitors during shipments of monomers.

Further testing and evaluation of this procedure was discontinued.

Summary of Chemical Choices

The final choices of chemicals and concentrations for evaluation are summarized in Table 6. It was felt that these chemicals would allow adequate evaluation of the feasibility of in-situ detoxification treatment because they represented a range of chemical types and problems.

TESTING

Laboratory testing involved establishment of the conditions of testing, fabrication of the special testing apparatus and actual performance of the tests. Two types of tests were conducted to more closely simulate field conditions:

1. Flow-through tests in which drainage of the system was allowed during the reaction

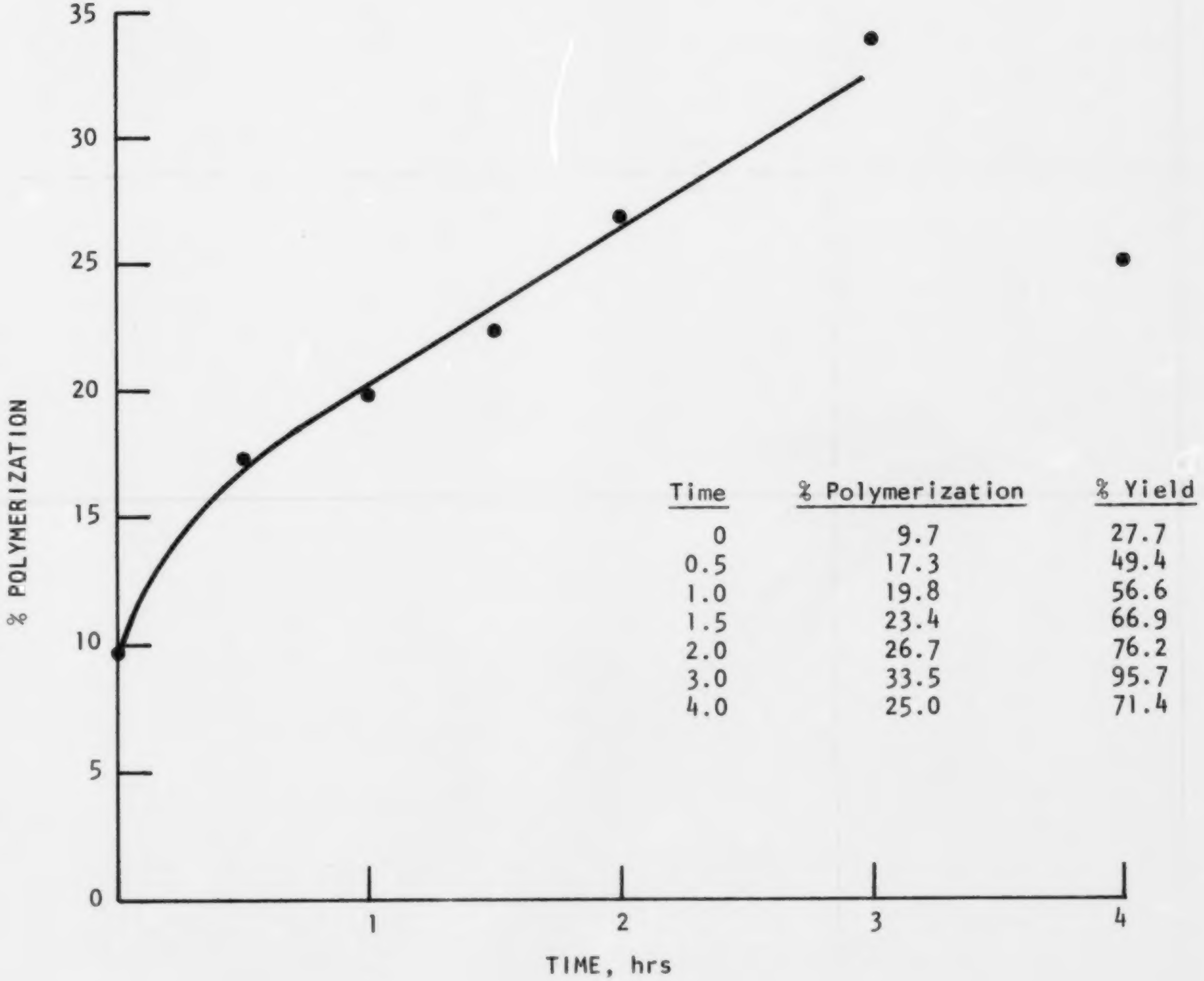
2. Sealed tests that involved the direct addition of reactant to the soil with no drainage allowed.

The flow-through tests are representative of conditions in gravel, sand and silt soils. The sealed tests are more indicative of contaminant flow-through in clays.

Experimental Design

The soil characterization test results were used as a basis for establishing the experimental design. The following conditions were considered to be the most important variables affecting in-situ detoxification:

EPA-287 (Cin.)
(4-76)



Time	% Polymerization	% Yield
0	9.7	27.7
0.5	17.3	49.4
1.0	19.8	56.6
1.5	23.4	66.9
2.0	26.7	76.2
3.0	33.5	95.7
4.0	25.0	71.4

Figure 2. Rate of styrene polymerization under favorable conditions.

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD. BEGIN SECTIONS HERE

TABLE 6. SUMMARY OF CHEMICAL SYSTEMS EVALUATED IN THE PROGRAM

Reaction type	Contaminant		Reactant	
	Compound	Concentration	Compound	Concentration
Oxidation/reduction	Sodium hypochlorite	12-15%	Sodium bisulfate	7.5%
Neutralization	Sulfuric acid	36N	Sodium hydroxide	1-5N
Precipitation	Copper sulfate	75 g/l	Sodium sulfide/ Sodium hydroxide	1.0 0.1
Polymerization	Styrene	100%	Persulfate	-

BEGIN LAST LINE OF TEXT
3/8"
FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

1. Unit dry weight--This represents the density condition that is directly related to the void (air and water) volume within a unit volume of the soil.

2. Water content--The initial water content is important with regard to contaminant flow in the soil and adsorption upon the soil surfaces.

3. Contaminant loadings--The percentage of voids that are filled by contaminant has an effect upon the way in which the contaminant and reactant interact, especially as related to intermixing of the chemicals and soil water.

4. Time of reaction--An evaluation of whether the reaction was instantaneous or time-dependent was conducted by forcing the reactant through the soil under pressure. The pressurized flow resulted in shorter contact time.

The actual test variables used in the experimental design tests were selected to model a range of possible in-situ soil conditions. These are summarized in Table 7. The densities selected were typical of average conditions, neither excessively loose nor extremely dense. The moisture contents were selected to represent either moist or saturated conditions. The void volume loadings of the contaminant were selected to represent both saturated conditions where the contaminant was totally contained within the ground surface or partially saturated conditions where the contaminant had flowed through the soil structure, partially filling the voids as it continued its flow. The time of reaction was evaluated by varying the pressure. For most tests, no pressure was utilized because this simulated natural contaminant and reaction flow through the soil. Some tests were pressurized, which accelerated the rate of contaminant flow through the soil. Comparison with the nonpressurized flow gave an indication of the rate at which the detoxification reaction was occurring.

In summary, the experimental design was based upon the following general concepts:

1. The soil was modeled at probable in-situ conditions. These included various moisture contents and densities, which resulted in various degrees of void space available for contaminant loading.

2. The hazardous contaminant was added to the soil surface at atmospheric pressure, simulating a spill condition. The amount of hazardous waste added was varied in order to simulate either standing fluid or transient flow conditions.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD; BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
3/8"
DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TABLE 7. SUMMARY OF LABORATORY TEST VARIABLES

Soil type	Bulk density, lb/ft³	Water content %	Saturation (water) %	Volume contaminated 100% voids cm³	Volume contaminated 50% voids cm³	Pressures P_1 psi	Pressures P_2 psi	Pressures P_3 psi
Gravel	94	3.0	9.1	562	281	0	-	-
Gravel	110	3.0	12.8	446	223	0	-	-
Sand	114	9.0	52.8	136	68.4	0	1	-
Sand	106	5.0	23.6	256	128	0	1	-
Sand	106	13.0	61.4	129	65	0	1	-
Sand	98	0	0	379	256	0	1	-
Silt	99	14.0	56	111	56	0	5	15
Silt	90	10.0	32	192	96	0	5	15
Silt	90	18.0	57	120	60	0	5	15
Silt	81	14.0	36	201	100	0	5	15
Clay	85.3	20.0	58	60	30	0	15	30
Clay	76.9	20.0	48	84	42	0	15	30

$Kg/m^2 = lb/ft^3 \times 16.018$

3. The amount of reactant added was based upon the amount of contaminant. The reactant was added at various pressures in order to determine the rate of reaction with the contaminant.

The variables are all somewhat interrelated. For example, as the bulk density of the soil increases, the void space within the soil structure decreases. The flow of contaminant through a soil structure is related to the available void volume that is not filled with water, as well as to the soil density. Also, the mixing of the contaminant and reactant is a function of the available volume, moisture condition and permeability.

Apparatus and Procedure Development

Special columns were prepared for use in the testing. A flow-through unit is illustrated in Figure 3. When it was needed, regulated air pressure was used to force the reactant through the contaminated soil. The sealed testing required elimination of base and drainage holes. Either acrylic or clear polyvinyl chloride was used, depending upon the chemicals that were being tested. Porous plates were placed on the soil surface to allow even distribution of the liquid. Soil preparation was similar for the two tests with a known weight of soil mixed with water and then packed into the column in layers to a specified height. Once the columns were packed, the contaminant was poured over the surface and allowed to penetrate the soil.

Some procedures were different for sealed and flow-through testing. For the sealed tests, a contaminant-soil contact time of 24 hours was used, after which time the calculated volume of reactant was added and allowed to react for 48 to 76 hours. Excess liquid retained on the surface was removed for analysis and a core sample was collected, sectioned into 1 to 2 cm long (0.4 to 0.8 in.) pieces and then analyzed.

The flow-through testing procedure involved the collection of fluid leaving the test column and the determination of excess contaminant before reactant addition. This procedure allowed calculation of the fraction of contaminant remaining or "entrained" within the soil. This entrained material was treated by reactant addition followed by a water rinse. For some tests, the system was pressurized to force the flow and to reduce detention time. In all cases, the time of liquid passage was noted. Discrete samples were taken and analyzed separately to determine reaction effectiveness. After rinsing the system with water, a clean water leach fluid was placed on the soil surface to simulate a 5 cm (2 in.) rainfall. Any liquid collected was analyzed and a final core sample was then obtained.

ANALYTICAL PROCEDURES

For the tests performed, all analyses were determined on the leachates from the tests and on water extracts from the soils tested.

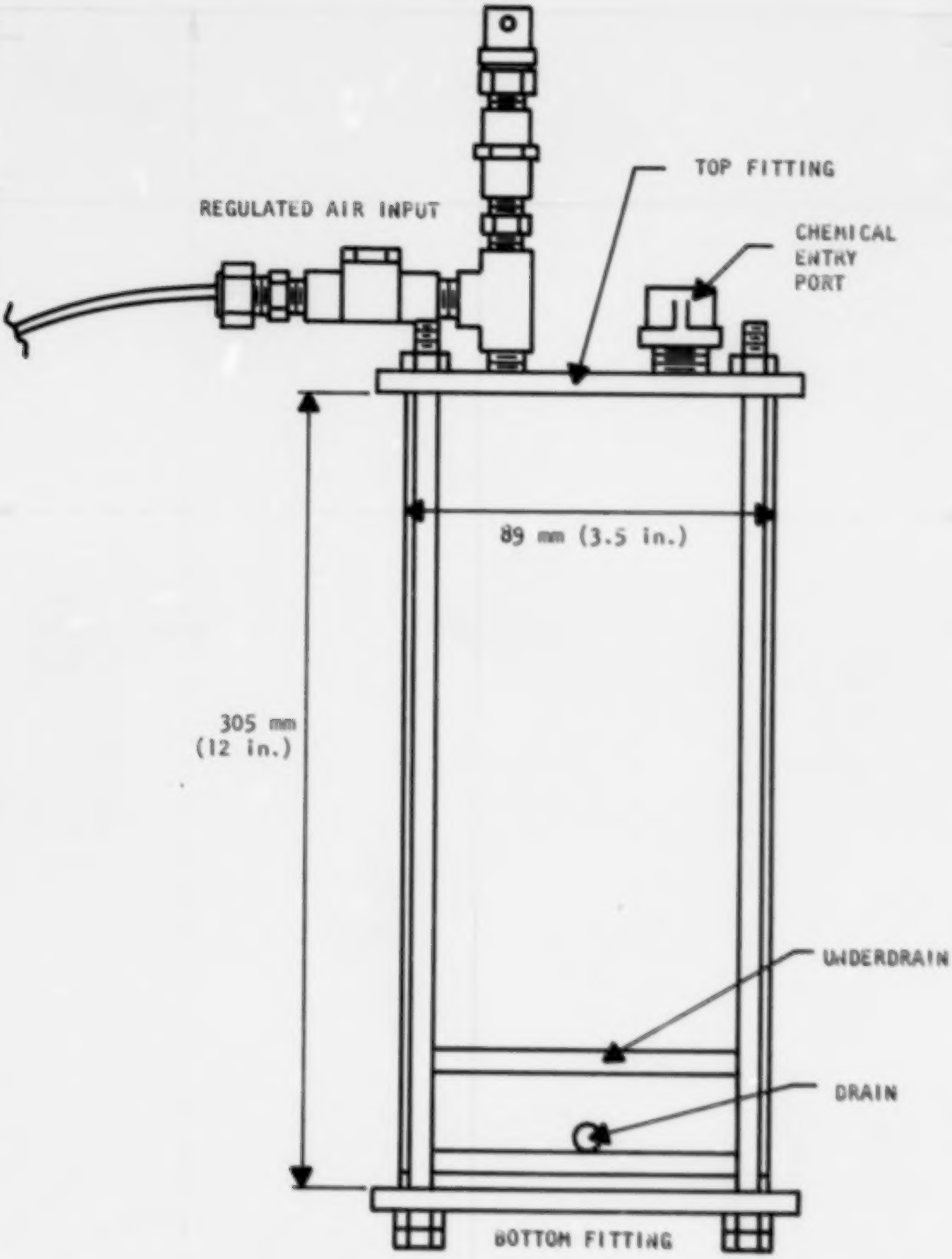

TOP FITTING
REGULATED AIR INPUT
CHEMICAL ENTRY PORT
89 mm (3.5 in.)
305 mm (12 in.)
UNDERDRAIN
DRAIN
BOTTOM FITTING

Figure 3. Schematic of test column.

The test contaminants and reactants, as well as the references for the analytical procedures used for their measurement are summarized below:

1. Neutralization
   a. The contaminant used was concentrated sulfuric acid, which was determined by Methods 402-4a, Standard Methods, 14th Ed., 1975.

   b. The reactant employed was sodium hydroxide (6N NaOH), which was analyzed by Methods 402-4a, Standard Methods, 14th Ed., 1975.

2. Oxidation/reduction
   a. The contaminant utilized was sodium hypochlorite and was measured by Method 409a, Standard Methods, 14th Ed., 1975.

   b. The reactant employed was sodium bisulfite, which was determined by Method 429, Standard Methods, 14th Ed., 1975.

3. Precipitation
   a. The contaminant was copper sulfate. It was analyzed for by Method 301a, Standard Methods, 14th Ed., 1975.

   b. The reactant used was sodium sulfide, which was determined by Method 428-3b, Standard Methods, 14th Ed., 1975.

4. Polymerization
   a. The contaminant used was styrene monomer.

   b. The reactant (initiator) utilized was potassium persulfate.

   c. The polymerized styrene was removed from the leachate by filtration, washed with methanol and water, dried and weighed. [This procedure was based upon information in Reference (6) and on a personal communication with Professor Koutski of the Chemical Engineering Department, University of Wisconsin-Madison, 1977.]

RESULTS AND DISCUSSION

Both types of treatment, sealed and flow-through, resulted in quite effective detoxification of the soil systems that were under evaluation. These tests established the potential feasibility of treating soil in place. However, the data must be carefully extrapolated because these results are basically limited to the situations that were under evaluation. The variability of soil types will make site specific testing imperative before final application. Nevertheless, the testing indicated the overall feasibility of in-situ detoxification of soil systems.

Flow-Through Test Results

The most significant result of the laboratory tests was that in-situ detoxification was possible and effective under the conditions tested. The measurement of total detoxification efficiency involved analyses of residual soil contaminant amount and amount of entrained contaminant. In this context, entrained is defined as the amount of contaminant remaining in the soil column after all the contaminant has been added and allowed to gravity drain from the packed soil. In Equation 1, residual relates to all contaminant amounts that remain after reactant and rinse water addition. The efficiency was calculated as follows:

$$\text{Total detoxification efficiency (\%)} = \frac{\text{Entrained contaminant amount} - \text{residual amount}}{\text{Entrained contaminant amount}} \times 100 \qquad (1)$$

In all flow-through testing, this total detoxification efficiency exceeded 99 percent. In both neutralization and precipitation reactions, the contaminant was completely gone and only traces of reactant remained in the soil. The amount of retained reactant seemed to depend upon soil type with the gravel and sand retaining smaller amounts (1 to 20 mg/kg for neutralization; 1 to 2 mg/Kg for redox) and the silt retaining higher amounts (1 to 40 mg/Kg for neutralization and 3 to 10 mg/kg for redox).

The variables influencing the detoxification can be grouped into four main areas. These variables will affect the use and design of the in-situ detoxification equipment.

1. Two mechanisms are involved in detoxification - displacement and direct reaction

2. Water rinse and excess liquid removal techniques help control and promote in-situ detoxification

3. Different soil characteristics (bulk density, contact time, water content and void loading) have an effect upon detoxification but the treatment efficiency was not directly proportional to any specific individual condition

4. The soil and chemical systems involved have a significant impact upon the effectiveness of detoxification.

The calculated detoxification results for the different chemical and soil systems tested are presented in Appendix Tables A-1 through A-3. These detailed results are summarized in Tables 8 and 9. A review of these tables is essential to the following discussion. To further aid in visualization of the discussion, Figure 4 schematically represents the steps in the test procedures and the calculations used in preparing the tables of results.

Detoxification Mechanisms--
Total detoxification appeared to be the result of two mechanisms. The first was displacement of fluid through the soil system. This displacement was noted through the tests by a piston or plug flow phenomenon and significant variations in concentration of the elutriated fluid. Figure 5 shows the generalized concentration trends during a test run.

Samples were collected before the violent reaction zone, during the reaction zone passage, after the reaction had passed, after all the rinse water was added, and after the 24-hour leach period. The heat of reaction was greatest at the zone of reaction. Samples were immediately analyzed for residual reactant and contaminant. The amounts of residuals were then summed to determine the percentage of contaminant flushed or displaced.

The second method of detoxification involved actual reaction of the contaminant and reactant in the soil system. This reactant was determined by calculating the difference between the amount of chemical added and that displaced. Because there was virtually no contaminant left in the soil after the test, it was assumed that all the remaining chemical was reacted. Another indication of reaction was the lower concentration of contaminant and reactant as measured in the collected samples. The highest reactant concentration measured was only one-half of that initially added. This indicated that the dilution was caused both by reaction and by the addition of entrained liquid. Water volume alone was not sufficient to cause the concentration reductions noted.

The reaction efficiencies were much more variable than the overall detoxification efficiencies and were given closer scrutiny during the evaluation. Reaction efficiency for neutralization in sand and gravel was much lower than that measured for other systems. This is because neutralization testing required a pre-rinse of water in the porous soils before reactant addition in order to control excessive heats of reaction. Therefore, much of the acid was rinsed from these soils without reacting at all. The lowered reaction efficiencies in these soils reflect this difference.

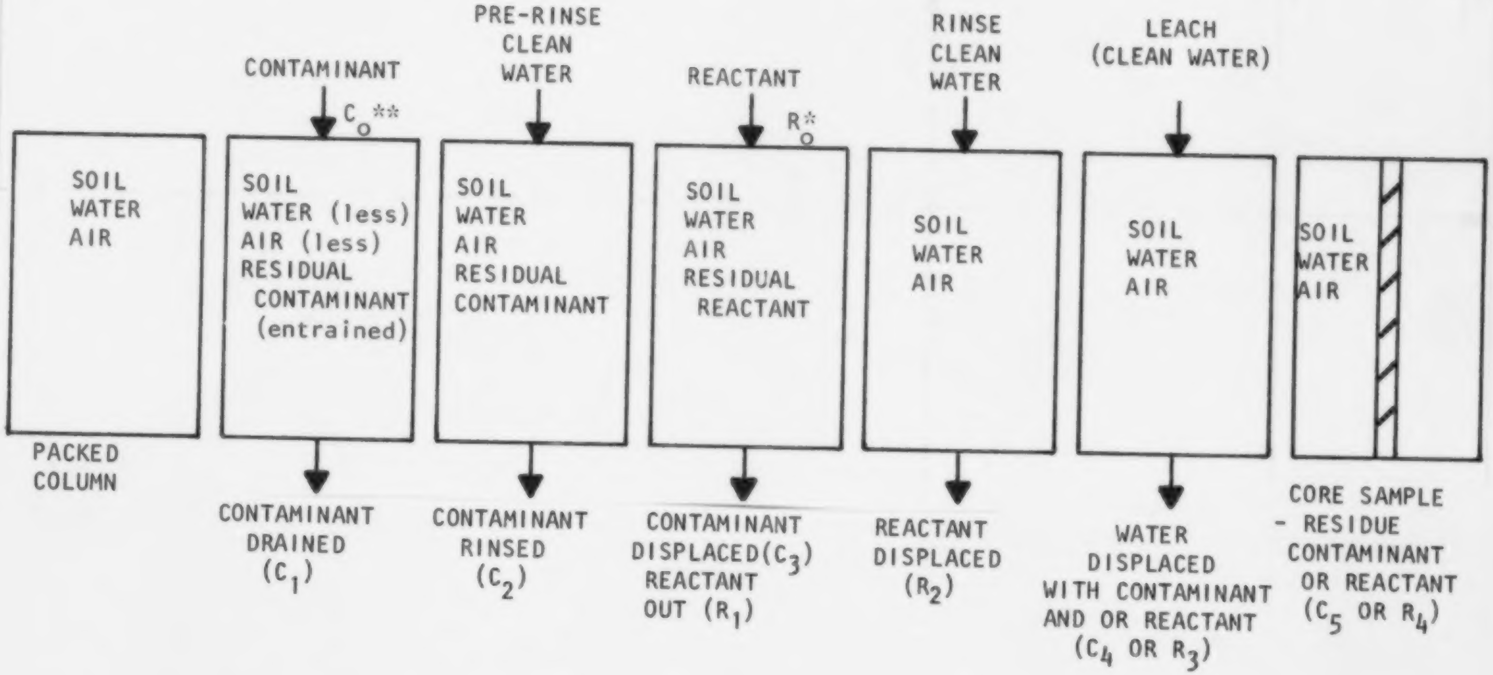
Water Rinse and Excess Liquid Removal Needs--
Because some of the contaminant was forced out (unreacted) by addition of rinse water or reactant, there was a reactant residual in some tests. A water rinse was necessary to remove excess reactant from the soils after treatment. For laboratory testing, two times the void volume of clean

TABLE 8. SUMMARY OF TREATABILITY STUDY RESULTS FOR FLOW-THROUGH TESTING

Soil and run no.	Reaction type	Percent contaminant entrained, avg.	Percent entrained contaminant reacted, avg.	Percent entrained contaminant displaced, avg.	Percent contamin. total reacted, avg.	Percent total contamin. detox., avg.
Gravel (1→4)	Redox	19.3 - 29.6 (21.6)	89.5 - 95.4 (93.6)	4.6 - 10.5 (6.32)	12.9 - 26.4 (20.0)	100 (100)
Gravel (31→34)	Neut.	15.4 - 25.3 (20.5)	5.5 - 34.8 (21.6)	65.2 - 94.5 (78.4)	3.7 - 5.8 (4.8)	100 (100)
Gravel (59→62)	Ppt	12.8 - 31.3 (20.4)	96.3 - 99.9 (98.5)	0.1 - 3.7 (1.4)	12.8 - 31.3 (20.0)	99.4- 99.9 99.7
Sand (5→16)	Redox	87.6 - 100 (98.0)	20.0 - 66.5 (37.7)	33.5 - 80.0 (62.2)	18.4 - 66.5 (37.3)	100 (100)
Sand (35→46)	Neut.	59.1 - 100 (88.8)	3.4 - 52.2 (25.2)	47.8 - 96.6 (74.8)	3.4 - 52.2 (22.3)	100 (100)
Sand (63→74)	Ppt	93.3 - 100 (97.9)	19.5 - 99.9 (43.6)	0.1 - 80.5 (56.4)	19.2 - 99.9 (41.8)	99.9- 99.98 (99.9)
Silt (17→28)	Redox	99.2 - 100 (99.9)	12.1 - 90.3 (57.3)	8.2 - 87.9 (42.6)	12.1 - 91.8 (57.3)	100
Silt (47→58)	Neut.	100 (100)	30.3 - 99.9 (57.7)	0.1 - 69.7 (42.3)	33.7 - 99.9 (57.7)	100
Silt (75→86)	Ppt.	96 - 100 (99.7)	42.1 - 99.2 (77.3)	0.8 - 57.9 (27.7)	42.1 - 98.7 (72.1)	99.1- 99.9 (99.7)

TABLE 9. TESTS FOR INTERNAL SOIL VARIABLE SIGNIFICANCE FOR FLOW-THROUGH TESTING

Soil and run no.	Reaction type	Average contam. entrained, %	Average contam. reacted, %	Average total detoxification, %	Significant variables	No. of tests
Gravel (1→4)	Redox	21.6	20	100	None	4
Gravel (31→34)	Neut.	20.5	4.8	100	Loading	4
Gravel (59→62)	Ppt.	20.4	20	99.7	None	4
Sand (5→16)	Redox	98	37.3	100	Detention time	12
Sand (35→46)	Neut.	88.8	22.3	100	Detention time	12
Sand (63→74)	Ppt.	97.9	41.8	99.9	Detention time	12
Silt (17→28)	Redox	99.9	57.3	100	Soil conditions	12
Silt (47→58)	Neut.	100	57.7	100	Loadings/soil conditions	12
Silt (75→86)	Ppt.	99.7	72.1	99.1	Loading	8


CONTAMINANT
C_o**
PRE-RINSE CLEAN WATER
REACTANT
R_o*
RINSE CLEAN WATER
LEACH (CLEAN WATER)
SOIL WATER AIR
SOIL WATER (less) AIR (less) RESIDUAL CONTAMINANT (entrained)
SOIL WATER AIR RESIDUAL CONTAMINANT
SOIL WATER AIR RESIDUAL REACTANT
SOIL WATER AIR
SOIL WATER AIR
SOIL WATER AIR
PACKED COLUMN
CONTAMINANT DRAINED (C_1)
CONTAMINANT RINSED (C_2)
CONTAMINANT DISPLACED(C_3) REACTANT OUT (R_1)
REACTANT DISPLACED (R_2)
WATER DISPLACED WITH CONTAMINANT AND OR REACTANT (C_4 OR R_3)
CORE SAMPLE - RESIDUE CONTAMINANT OR REACTANT (C_5 OR R_4)

*R_o - Established by residual (entrained) contaminant amount.
** - All amounts calculated on a weight basis.

Calculations Involved:

1. Percent contaminant entrained (C_e) $= \left[\frac{\text{Contaminant added } (C_o) - \text{Contaminant drained } (C_1)}{\text{Contaminant added } (C_o)}\right] \times 100$

Continued

Figure 4. Flow-through test procedure and equations for calculation of results.

2. Percent entrained contaminant reacted (C_R)

$$= \left[\frac{\text{Entrained contaminant } (C_e) - [(\text{Contaminant rinsed}(C_2) + \text{Contaminant displaced } (C_3) + \text{Water displaced } (C_4) + \text{Residual contaminant } (C_5)]}{\text{Entrained contaminant } (C_e)} \right] \times 100$$

3. Percent entrained contaminant flushed (C_F)

$$= \left[\frac{[\text{Entrained contaminant } (C_e) - \text{Residual contaminant } (C_5)] - \text{Contaminant Reacted } (C_R)}{\text{Entrained contaminant } (C_e) - \text{Residual contaminant } (C_5)} \right] \times 100$$

4. Percent total contaminant reacted (C_T)

$$= \left(\frac{\text{Contaminant added } (C_o) - \text{Contaminant drained } (C_1) - \text{Contaminant flushed } (C_F)}{\text{Contaminant added } (C_o)} \right) \times 100$$

5. Percent total contaminant detoxification

$$= \left(\frac{\text{Contaminant added } (Co) - \text{Contaminant residual } (C_5)}{\text{Contaminant added } (C_o)} \right) \times 100$$

Figure 4 (Continued).

BEGIN FIRST LINE OF TEXT
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA

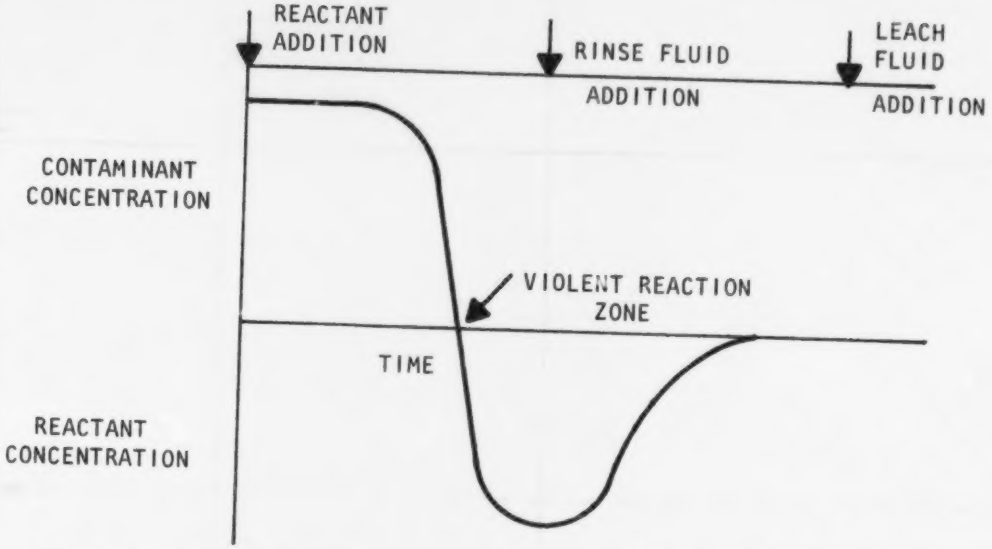


Figure 5. Generalized concentration trends in flow-through testing.

water was effective. However, addition of this large volume of fluid required provision for excess liquid removals in a soil system. This was not a problem in the flow-through laboratory columns; however, during field applications, either a wet well or a pressure relief well with a pump for removal of this rinsing fluid would be mandatory.

Effects of Varying Soil Bulk Density, Contaminant Loading and Detention Time--
The statistical significance of the three main variables studied (soil bulk density, contaminant loading and detention time) was evaluated and was not consistant among soil types and chemical systems. An F test for significance, using an analyses of variance (ANOVA) comparison, was performed. The results, summarized in Table 9, indicated that none of the variables could be consistently correlated to reaction efficiency for all soil or reaction types. However, some observations can be made about the observed impacts of the variables.

The bulk density of the soils, as well as the percentage of voids being filled affected the amount of contaminant that was entrained in the soil. As expected, when more contaminant was added to the system, a greater volume was entrained. However, less contaminant was entrained when expressed as a percentage of the total contaminant added. The higher bulk densities affected the amount of contaminant entrained. The trend of higher bulk densities and higher amounts of contaminant entrained was most noticeable in the silt. This could be correlated to the greater surface area available for adsorption on the more tightly packed (denser) silt.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

The impact of other variables on the reaction efficiency had a much less defined effect. Detention time appeared to affect sand reaction efficiencies. The longer the contact time, the higher the reaction efficiency. Void loadings, soil bulk and moisture contents had significant impact on silt detoxification. The trend with silt was to have a higher reaction efficiency with lower contaminant loadings. The higher volume of contaminants had a tendency to be displaced more easily and this displacement lowered the effectiveness of reactions, although the overall detoxification was not affected.

In general, the variables investigated did appear to affect the components of detoxification (i.e., displacement and reaction). However, the overall contaminant detoxification was not affected and remained high for all tests performed.

Impact of Soil Types and Chemical Systems--

Trends within the soil types and chemical types were more evident. Because the soil types were specifically chosen to minimize interaction with chemical systems, the effects can be considered separately.

Gravel soils had the least amount of reaction detoxification. This observation is understood through consideration of the large amount of material that was lost from the soil before any reactant addition. The porous nature of the gravel allowed most of the contaminant (71 to 88 percent) to pass out of the column before treatment. However, the material that was entrained was effectively treated with both redox and precipitation reactions. Little additional flushing or displacement occurred. It appeared as though the entrained contaminant was tightly bound to the gravel and was reacted rather than displaced. Neutralization did not follow this trend because of the pre-reactant rinse, which was necessary to control the heat of reaction. The rinse lowered the amount of contaminant remaining in the soil and consequently lowered the reaction efficiency. However, the overall detoxification was still quite high and residual contaminant and reactant concentrations were low.

Sand systems provided a higher reaction efficiency than gravel soils did. Most of the contaminant remained entrained in the soil, especially when 50 percent loadings were used. Precipitation efficiencies were slightly lower than efficiencies achieved by other reactions because of the formation of a precipitate that blocks passage of reactant through established pathways. Neutralization again had a lower reaction efficiency because of the pre-reactant rinse. All residual soil contaminant concentrations were low, less than 20 mg/Kg. Overall treatment efficiencies based on residual concentrations exceeded 99.9 percent.

Silts retained the highest percentage of added contaminants. The extent of reaction in silt was highest of the soil types tested for the flow-through testing, possibly because the detention time was much longer. Generally, detention times for the silts were greater than 24 hours, compared to approximately 2 to 3 hours for sand and less than one hour

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

for gravel. The reactions yielding soluble products (redox and neutralization) had similar reaction effectiveness because a pre-rinse was not needed in this system. Again, the precipitation effectiveness was much higher (72 compared to 57 percent) possibly as a result of the blockage of established pathways by the formed solid. The concentrations of residuals in the soil were somewhat higher for silts, ranging from 1 to 40 mg/Kg. This phenomenon may be traced to the difficulties in forcing movement in closer packed soils. However, concentrated zones of contaminant or reactant were not found in the soils and the detoxification efficiency still exceeded 99 percent.

Sealed Test Results

Treatment of spills onto fine grained soils using a surface treatment approach resulted in surprisingly effective in-situ detoxification. The test procedure and calculation approach is schematically illustrated in Figure 6. Table 10 summarizes the results from the sealed tests and a detailed presentation of the data is included in the Appendix, Tables A-4 through A-6.

We did not perform complete sets of tests to evaluate the sealed approach. However, a number of tests were performed at different soil conditions and contaminant loadings in order to define the general feasibility of the approach. The preliminary conclusions drawn from this phase of the testing are:

1. Migration of the contaminant into the soil layers was quite limited in fine grained materials
2. Sealed or surface detoxification appears to be an effective method for spill treatment in fine grained soils.
3. Detoxification was most effective in the upper layers of the contaminated soil.

Migration Rate--

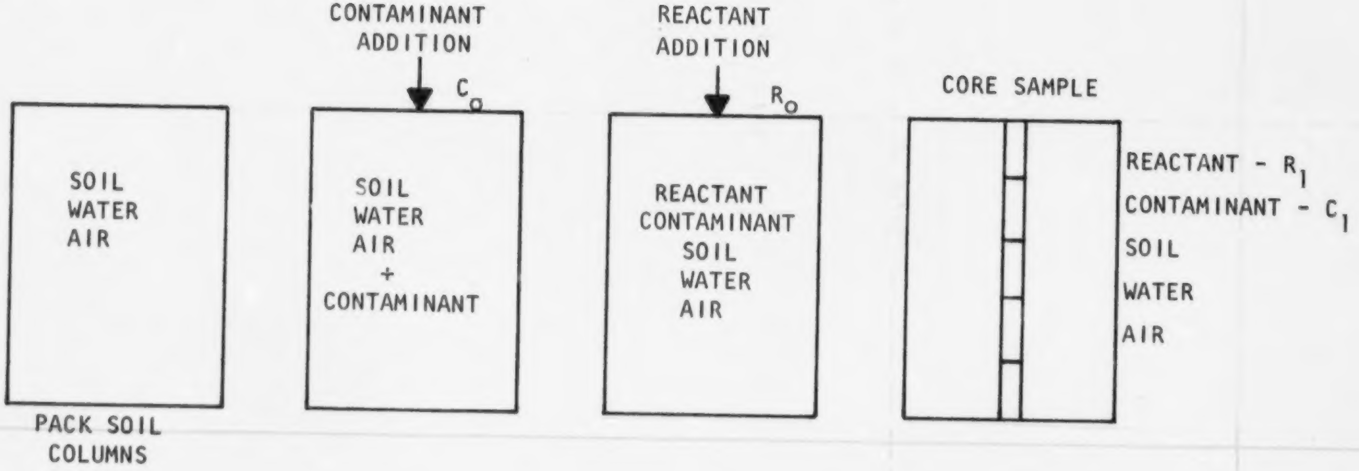
Some preliminary evaluations were performed to establish the migration rate of the contaminant through the soil. The average results of the tests are presented in Figure 7. Approximately half of all contaminants remained entrained in the top centimeter of soil after 48 hours. Variations in migration appeared to be correlated to bulk density, as was anticipated. The low migration rate is significant because it indicates that surface treatment (to reduce an imminent hazard) followed by excavation may be a viable approach.

Effectiveness of Reaction--

The effectiveness of the sealed detoxification system was calculated and the results are summarized in Table 10. The overall efficiencies of redox reactions were the highest of all reactions for the three soil types. The neutralization and precipitation efficiencies were approximately the same.

EPA-287 (Cin.)
(4-78)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE


CONTAMINANT ADDITION
C_o
REACTANT ADDITION
R_o
CORE SAMPLE
SOIL
WATER
AIR
PACK SOIL COLUMNS
SOIL
WATER
AIR
+
CONTAMINANT
REACTANT
CONTAMINANT
SOIL
WATER
AIR
REACTANT - R_1
CONTAMINANT - C_1
SOIL
WATER
AIR

1. $$\underset{C_R}{\text{PERCENT CONTAMINANT REACTED}} = \left(\frac{\text{CONTAMINANT ADDED } (C_o) - \text{CONTAMINANT RESIDUAL } (C_1)}{\text{CONTAMINANT ADDED } (C_o)}\right) \times 100$$

2. $$\underset{C_1}{\text{PERCENT CONTAMINANT REMAINING}} = \left(\frac{\text{CONTAMINANT RESIDUAL } (C_1)}{\text{CONTAMINANT ADDED } (C_o)}\right) \times 100$$

3. $$\underset{R_1}{\text{PERCENT REACTANT REMAINING}} = \left(\frac{\text{REACTANT RESIDUAL } (R_1)}{\text{REACTANT ADDED } (R_o)}\right) \times 100$$

Figure 6. Sealed test procedure and equations for calculation of results.

3/8"
PAGE NUMBER
FOR TABLES AND ILLUSTRATIONS
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

TABLE 10. SUMMARY OF SEALED TESTS

Soil and run no.	Reaction type	Percent contaminant reacted, avg.	Percent contaminant remaining, avg.	Percent reactant remaining, avg.
Sand (87→89)	Redox	73.6 - 95.5 (82.5)	4.5 - 26.4 (17.5)	7.6 - 60.5 (30.2)
Sand (100→103)	Ppt.	78 - 99.7 (88.4)	0.3 - 22.0 (11.6)	0 - 22.3 (7.6)
Silt (90→91)	Redox	89 - 98.6 (93.8)	1.4 - 11 (6.2)	1.7 - 12 (6.9)
Silt (96→97)	Neut.	9.4 - 79.5 (44.5)	20.5 - 90.6 (55.6)	2.2 - 21.7 (12.0)
Silt (104→107)	Ppt.	35.1 - 75.6 (51.8)	24.4 - 64.9 (48.3)	0.0 - 9 (2.75)
Clay (92→95)	Redox	96.2 - 99.5 (98.0)	0.5 - 3.8 (2.0)	0.2 - 4.0 (1.8)
Clay (98→99)	Neut.	74.6- 78 (76.3)	22 - 25.4 (23.7)	0 - 0 (0)
Clay (108→111)	Ppt.	56.5-87.0 (74.6)	13.0-43.5 (25.5)	0 (0)

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

Depth, cm	Avg. Contaminant % Per Layer Cu	Acid	Cl
1	57.8	53.3	49.4
2	31.2	28.4	31.2
3	8.6	15.0	15.7
4	1.9	3.5	3.1
5	0.5	0.1	0.6

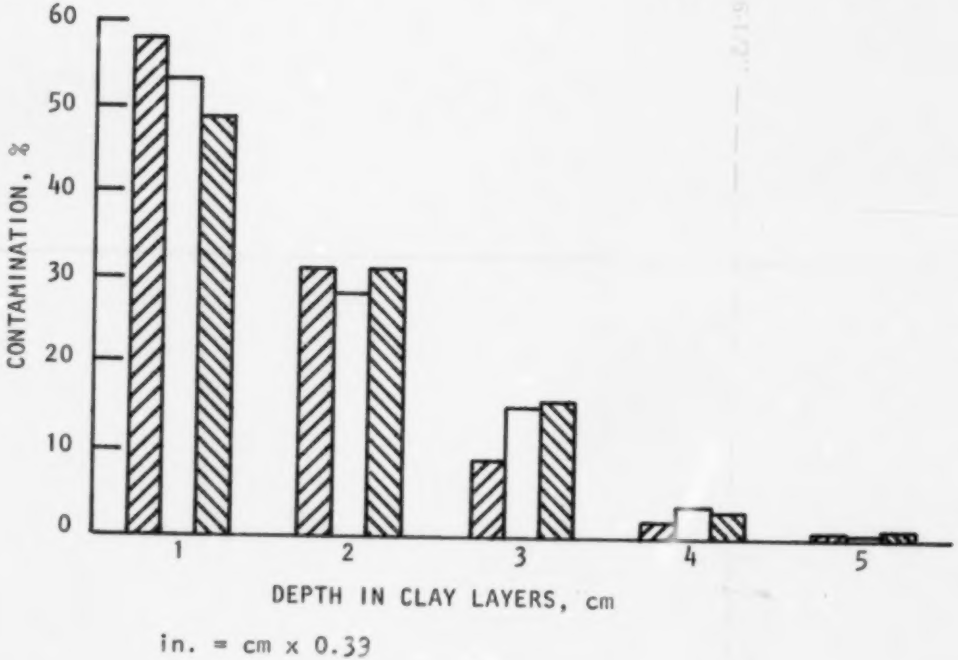


Figure 7. Average results of contaminant migration during sealed tests.

Tests performed on sands and silts demonstrated that surface treatment was not as effective as treatment in a flow-through system. However, it still may be desirable to use the sealed approach for silt and clays depending upon the overall permeability of the soil and the amount of void space available for treatment. Surface tests on clay soils were the most promising. They had contaminant removal efficiencies of 56 to 99 percent. Without the addition of dilution water, the residual amount of reactant was low for the finer grained soils.

Detoxification by Position in the Soil Profile

For some tests, the extent of detoxification was evaluated by position in the soil profile. The most effective removal occurred in the top layers of soil. The extent of removal was significantly affected by bulk density. The initial concentrations and removed amounts of copper contaminant in clays are presented in Figure 8. As illustrated in Figure 8, in tightly packed (highest relative density) soils, approximately 96 to 99 percent removal occurred in the upper one centimeter, which also retained 72 percent of the contaminant. There was an increase in contaminant concentration in lower soil levels; this increase can possibly be attributed to migration through surface cracks or to inaccurate initial concentration measurements in the lower layers.

Results from the redox system tests indicated that a slight residual reactant concentration remained in the top layers and a slight contaminant concentration remained in lower layers. These results appear to indicate the passage of a reaction front through the fine-grained soils. However, the concentrations of most measured residuals were quite low.

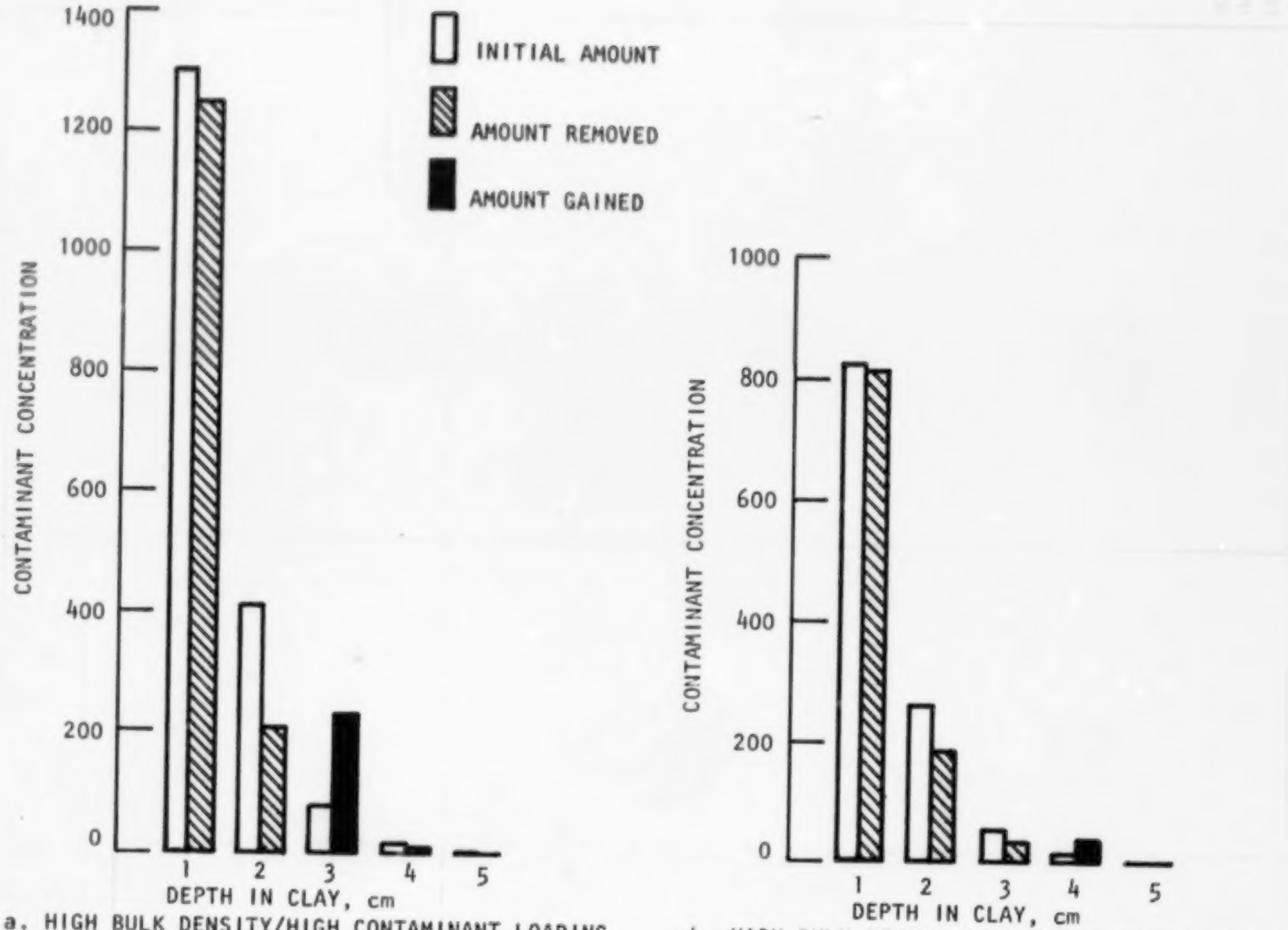
Summary of Sealed Testing--

The sealed testing approach is apparently a feasible alternative for treating certain spills on fine grained soils. The technique must be carefully evaluated when it is used on only small amounts of slightly contaminated soils. However, it can be used to reduce the hazard and to make subsequent handling and disposal safer and easier. The main concerns associated with sealed treatment are the available void volume, depth limitations and the need to provide a surface contaminant device that will allow slow percolation of the reactant into the soils.

APPLICABILITY OF TREATABILITY TEST RESULTS TO LARGER SCALE SYSTEM USE

The results of the treatability testing must be evaluated through a consideration of the ultimate use of *in-situ* treatment units for in-place detoxification. Injection treatments will be limited to use with sands and some silts. Generally, contaminant entrainment in gravel is relatively low, however, gravel may be treated if the amount and hazard of the entrained contaminant merits additional handling. Fine grained soils, clays and some silts, will not be treatable with injection procedures although a surface flooding treatment technique could eliminate or significantly reduce the hazard created by the spill.

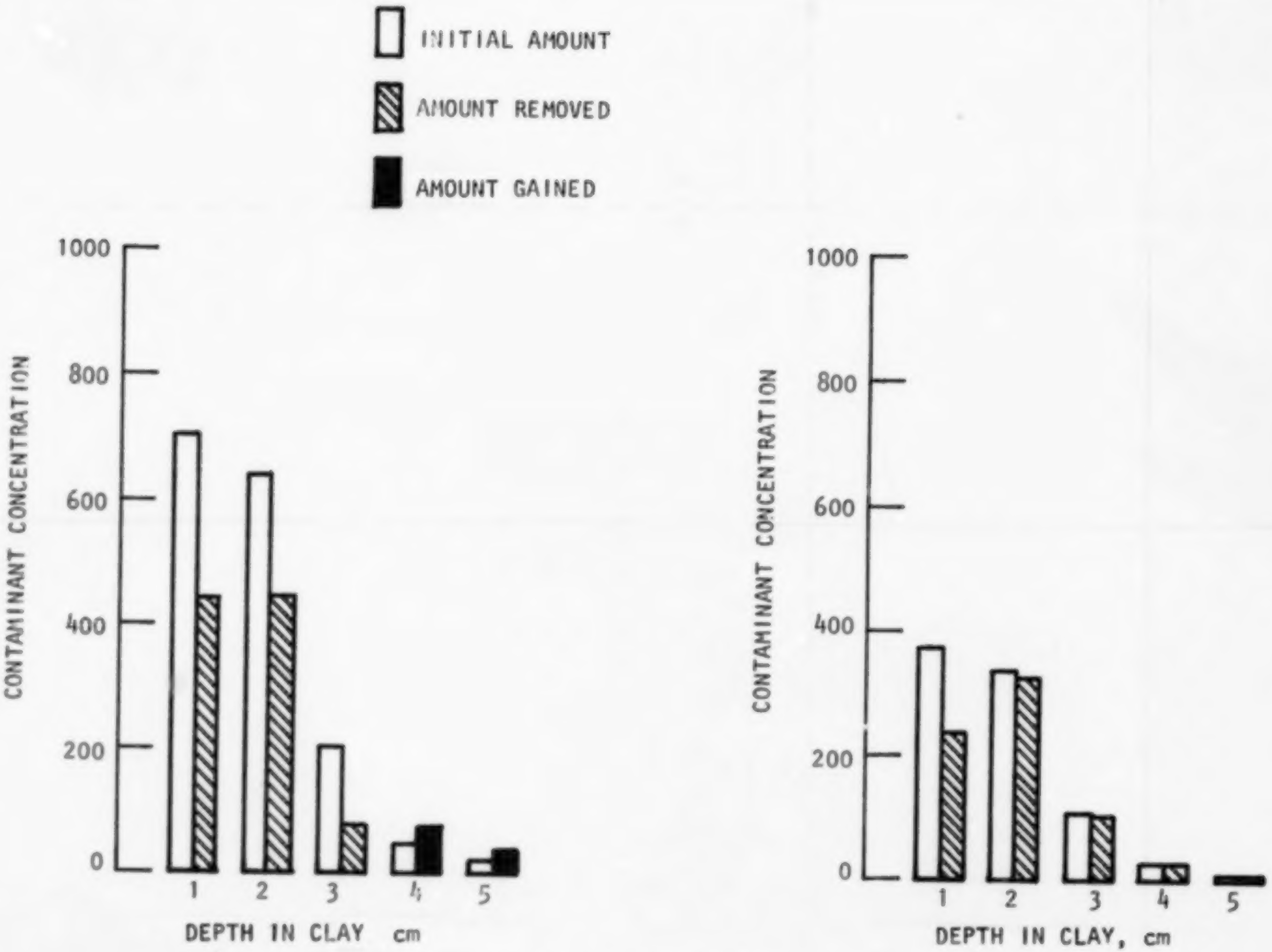
EPA-287 (Cin.)
(4-76)



a. HIGH BULK DENSITY/HIGH CONTAMINANT LOADING

b. HIGH BULK DENSITY/LOW CONTAMINANT LOADING

Figure 8. Copper contaminant concentrations with depth in clay for various bulk densities and contaminant loading.



c. LOW BULK DENSITY/HIGH CONTAMINANT LOADING

in. = cm x 0.39

d. LOW BULK DENSITY/LOW CONTAMINANT LOADING

Figure 8. (Continued)

In-situ treatment methods are not applicable to all types of spilled chemicals, and care must be taken when extrapolating the results obtained in these tests to other situations. Most inorganic materials and those organics that are soluble in water or treatable by inorganic reactants may be detoxified in-place. It must be recognized that the chemical characteristics of the soil can affect the reaction and so they must be taken into account on a site specific basis. In the laboratory feasibility tests, reactions that formed either soluble or insoluble reaction products allowed effective detoxification of the soil. Although precipitate formation increased detention times, it did not preclude detoxification. However, precipitate formation may require closer spacing of chemical injectors and wet wells because of the higher pressure that could be required to force fluids through the precipitate-blocked soils.

In some instances the procedures may not be appropriate. Potential problems exist in the treatment of organic contaminants or unidentified mixtures. Lab or field testing of samples from the site in question will be mandatory in these situations.

Another significant factor in large scale systems is the amount of contaminant that can be detoxified per unit volume of soil. For example, for a contaminant spilling on a gravel surface, there is a large available void space that could be filled. However, the contaminant flows by gravity through the open graded soil and thus, only a small amount of contaminant is retained on a unit volume basis. Consequently, the total volume of soil that could be contaminated by a spill onto gravel may be much larger than the volume contaminated by the same size spill on a sandy soil and may be too large to effectively treat. Therefore, the contaminated soil volume directly affects the size and amount of the grout contaminant envelope required. The amount of entrainment appears to be related to the grain size of the soil. Figure 9 conceptually shows the actual amount of entrainment versus soil type for the flow-through testing in which the initial contaminant addition was equal to 100 percent of the available void space within the soil structure.

The relationship between the amount of contaminant entrained and the amount flushed as the reactant is added can have a significant effect upon the amount of reactant required. This relationship must be considered so that an excess of reactant is not left within the soil. Figure 10 shows the approximate relationships for the redox reaction. Similar relationships could be developed for the other reactions and other soil types.

A main objective of this testing was to determine the general feasibility of in-place detoxification. The treatability tests have shown that the technique has promise; however, direct extrapolation of the results to a field situation should be avoided. The difficulties of extrapolation are even more severe when more complicated chemical reactions are considered. Possible problems of pH or site limitations, as well as soil/chemical interactions, can adversely affect in-situ detoxification in an unpredictable manner. On-site testing is essential to provide an indication of chemical demand and treatment effectiveness.

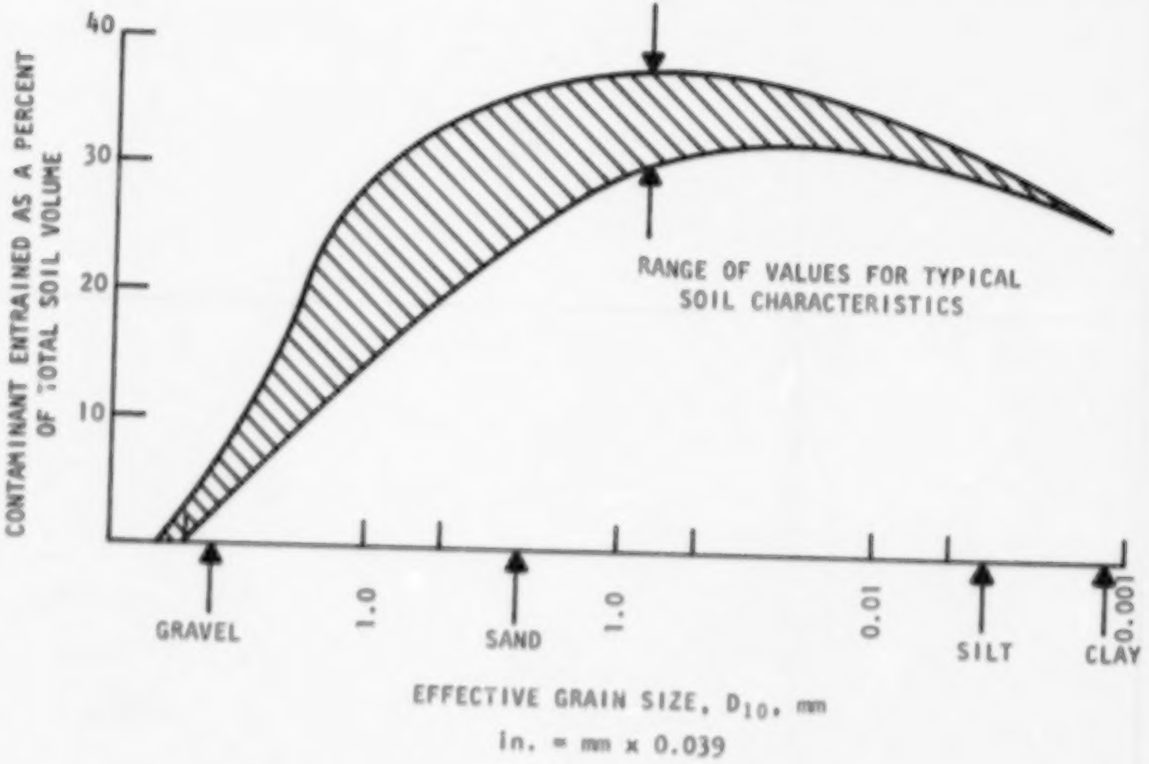


Figure 9. Contaminant entrainment versus soil particle size.

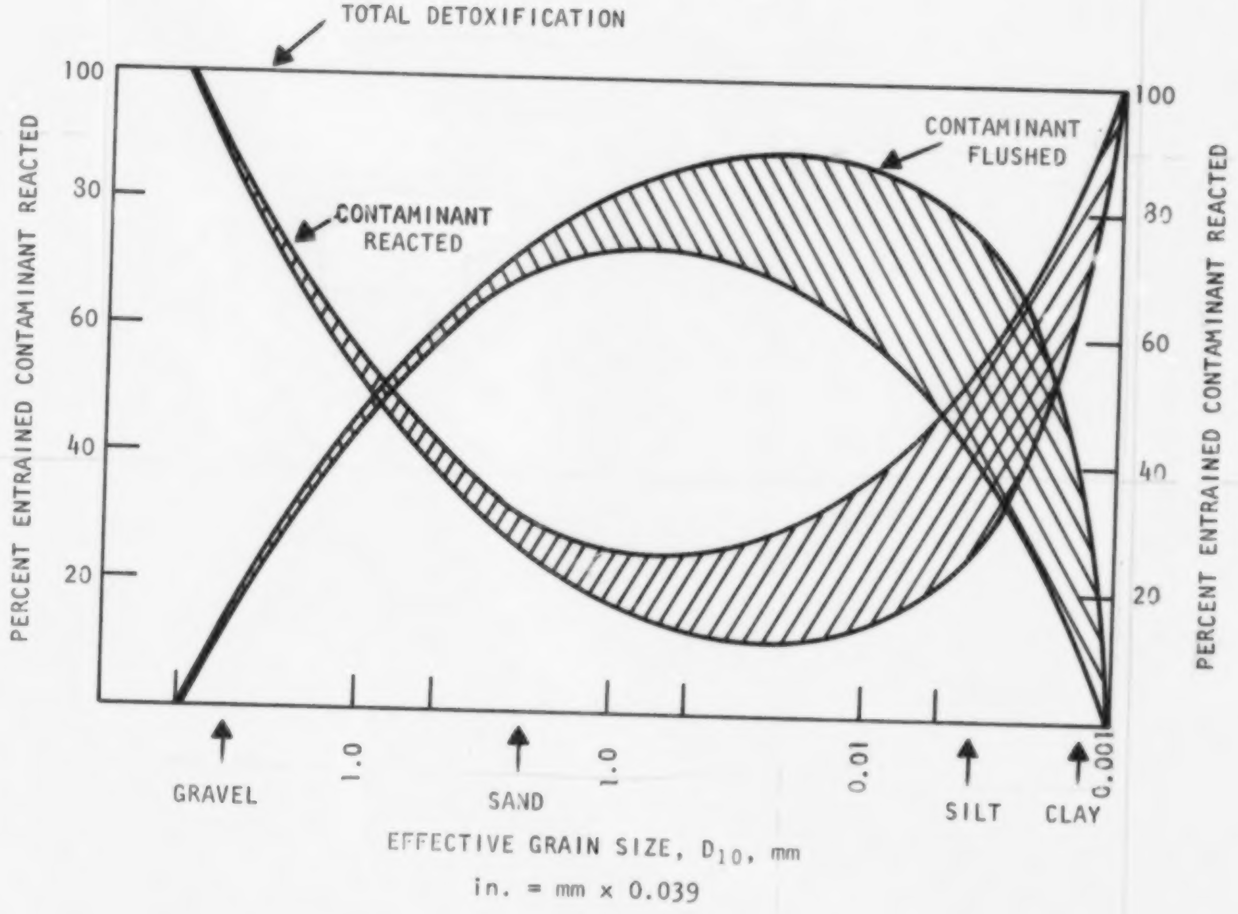


Figure 10. Relationships between entrained contaminant reacted and flushed versus soil particle size.

EPA-287 (Cin.)
(4-79)

SECTION 5

GROUT AS A SPILL CONTAINMENT MECHANISM

Various types of grout have been used for many years to help stabilize soils or to reduce water seepage through soils. This section of the report evaluates grouting techniques that may be used to contain a spill by forming a temporary or semi-permanent envelope around the spill. Concepts relating to the selection of various grouts, injection methods and grouting techniques are discussed. New state-of-the-art grouting techniques that may be adaptable to the equipment developed in this project are included in Section 8.

GROUT CONTAINMENT TECHNIQUES

A grout is a fluid that is pumped into the soil; this fluid will harden in place. Grouts are used to restrict ground water flow or to solidify and stabilize the ground. They are generally injected into the ground through a pipe or series of pipes that have been inserted to the desired soil depth. As the grout is injected into the soil, it tends to flow into more permeable soil layers, cracks or other channels. For spill containment, the most important requirement of the grout is not strength, but its ability to reduce the permeability of the soil. The purpose of the grout is to delay or restrict continued lateral and downward movement of the contaminant long enough to detoxify it.

The grout, which is under pressure, will flow into the same seams, channels and permeable soil zones that the contaminant would normally enter. However, if the grout arrives before the contaminant and hardens sufficiently, it should effectively minimize the flow of the contaminant. The grout, which retains its integrity long enough to allow in-situ detoxification, may form either a permanent or temporary barrier to contaminant flow. Figure 11 shows a schematic of grout flowing through soils.

It must be recognized that although grouting reactions and flow characteristics can be well defined in a laboratory situation, it is much more difficult to predict in-situ groutability. Grouting is largely a "state-of-the-art" technique and not an exact science. For successful completion, it requires careful, controlled handling by experienced operators. There will always be some uncertainty with regard to the actual flow paths of grout in the soil because subsurface soil conditions can never be completely defined, even after thorough on-site evaluation programs.

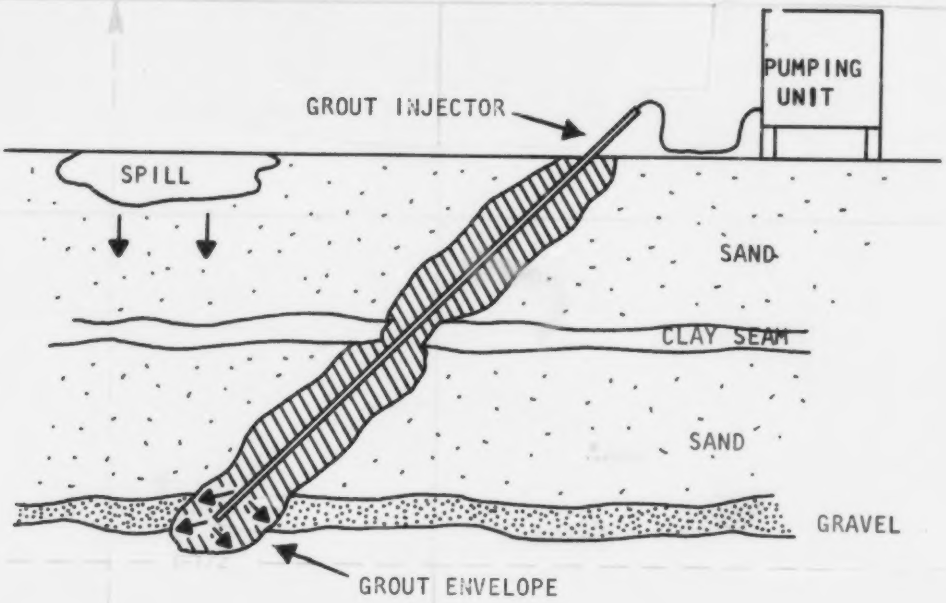


Figure 11. Schematic of grout flowing through soil.

The containment of a spill must be accomplished quickly. Thus, the optimum containment device would consist of a mobile injection system that could provide both lateral and vertical barriers to the downward flowing contaminant. To meet these requirements, the equipment should be simple to operate, and the grout injection system simple to install.

After a review of various techniques, it was decided that the formation of the grout envelope by closely spaced grout injectors, driven on an angle from around the edge of the spill, would be the best method for meeting a majority of the project's spill response objectives. Angle driven grout injectors were selected so that a direct path is not provided to the groundwater, a circumstance that could occur with injectors that are driven directly through the contaminated soil.

GROUT SELECTION

It is desirable that the grout be neither toxic nor permanent, although the former is the more critical requirement. Grouts are typically classified in two major categories--chemical and particulate. Chemical grouts can be used in finer grain soils, but such grouts are more toxic than particulate grouts. In particular, one of the most successful grouts, AM-9, is highly toxic and has been removed from most markets because of its potentially hazardous effects on the groundwater*. Other chemical grouts include ligin and formaldehyde-based grouts. These were also considered toxic and potential pollutants to the groundwater (8) and, therefore, were not further evaluated.

---

*Personal communication with American Cyanamide Corporation (1978).

Grouts that have a relatively low toxicity include silicates, bentonite and Portland cement grouts. Of this group, the chemical silicate grouts can be used in a much wider range of soil types. Both cement and bentonite grouts are particulate grouts, which are limited in their flow capabilities because of their higher viscosity and their inability to enter small pores in the soil structure. Silicate grouts are formulations of several chemicals, which, prior to setting, have viscosities similar to water and can be pumped through finer grained soils than can particulate grouts. Silicate grouts can typically be used for gravel, sands, silty sands, sandy silt, and most other granular soils that have only a small fraction of clay sized particles. The particulate grouts can only be used for gravel and coarse or uniformly graded sands. Figure A-1, Appendix, shows the ability of various grouts to penetrate different soil formations.

Silicate Grouts

Sodium silicate is the principal component of silicate grouting systems. Sodium silicate is alkaline, thus an acidic reactant is utilized to form colloidal silica, which then aggregates into a gel. Typical reactants include chlorine, ammonium salts, bisulfates, bicarbonates, sulfur dioxide and sodium silicofluoride. Metal salts may also be used. A grout mix using a low concentration of sodium silicate will provide the same permeability reduction (for days, months or years) as a mix using a high concentration, but it will not supply the strength of a high concentration mix that is sometimes required for soil stabilization. However, high strength is neither desirable nor essential for spill response containment.

Some silicate grouts may be semi-permanent and may partially break down over a period of months or years. Sodium bicarbonate has been reported (9) to be one reactant that allows the grout to exhibit these tendencies. Other reactants tend to form more permanent grouts. To minimize secondary impacts and allow an affected area to return to near pre-spill conditions as soon as possible, it may be desirable for the grout system to break down in time, after the contaminant has been detoxified.

Some limitations in the silicate system may be a result of their gel formation, which, as noted, is based upon an alkaline acid reaction. Therefore, silicate grouts may not be suitable for either highly acidic or highly alkaline conditions without substantial field adjustments. Section 8 of this report provides more details about these limitations.

Bentonite/Cement Grouts

A typical bentonite grout consists of water and 5 to 20 percent bentonite by weight. A small percentage of cement, or cement and a fluidizer can be added to the mixture. Bentonite/cement grouts are generally applicable for soils ranging from gravel to coarse, or uniformly graded sand sizes that have very few fines (particles smaller than a U.S. No. 200 sieve, 0.074 mm, 0.003 in.). Bentonites are naturally occurring clays and would

EPA-287 (Cin.)
(4-76)

represent no increase in toxicity to the subsurface conditions. In some situations, bentonite grout may be considered temporary, i.e., subject to longer term degradation by flowing groundwater. In most instances, bentonite grouts are less effective than silicate grouts.

SUBSURFACE CONDITIONS REQUIRING GROUTING

It may be assumed that 24 hours will be required from the notification of a spill event until actual mobilization of an *in-situ* detoxification system. The vertical flow of contaminant through various soil types during this 24 hour period becomes an important consideration. Based upon the laboratory permeability testing of the soils studied, the flow rates would be approximately:

Gravel--9.5 m/day (31.0 ft/day)
Sand--0.75 m/day (2.5 ft/day)
Silt--0.004 m/day (0.014 ft/day)
Clay--0.00006 m/day (0.0002 ft/day)

These values indicate the inherent limitations of an *in-situ* system that relies upon a grout envelope to prevent the further infiltration of a contaminant prior to neutralization. A waste spill on open graded gravel would flow beyond the range of the grouting system during the 24 hour mobilization period. On the other hand, a spill upon clay or fine silt would seep only a centimeter or two into the soil during that same time, indicating that other methods of containment and treatment at the surface would be more applicable.

A detoxification system for quick response to spills would be most effective for a well-graded sand and gravel mixture, ranging in gradation to silty, fine sand soils. These soil types are prevalent at the ground surface of about 45 percent of the surficial area of the Unites States (10). However, the actual soil profile and special site conditions may severely limit the groutability to a much smaller percentage of the areas in which suitable soils may exist. The limitations are further discussed in Section 8.

GROUT INJECTION DEVICES

There are many types of grout injection devices available. Many of these devices have been designed for specific grouting situations. Grout injectors can be inserted into the soil either by driving or by placement in a predrilled hole. Driving is accomplished by a drop hammer or by a pneumatically controlled percussion hammer. When injectors are placed in a predrilled hole, a packer type device that seals the hole above and below the depth at which grouting is to be performed is usually used. The Tube a Manchette is a common patented packer device. This system provides more positive control of grout injection, but requires much more time. It is typically used to grout a specific soil layer or to grout bedrock. For the grouting of an impermeable envelope around a spill, the time required for the injection operations should be minimized. An injection rod, driven directly into the soil, is the quickest and simplest method.

Several types of injection rods were evaluated. Standard drill rods, such as "EW" size or "AW" size, with outside/inside diameters of 35/22 mm (1.38/0.87 in.) and 44/31 mm (1.73/1.22 in.), respectively, were evaluated. These heavy duty rods were initially considered because of their long term usefulness, retrievability and potential for chemical, as well as grout, pumping. Subsequent evaluation indicated that most soil situations could be handled by a 19 mm (0.75 in.) inside diameter, heavy-wall black pipe, which is commonly used by grout contractors. The heavy-walled black pipe was eight times less expensive (1979 dollars) than the standard drill rod and, although more susceptible to bending and less durable, it was much more cost-effective. Heavy-wall black pipe rods are readily available throughout the country (in most well supplied hardware stores) and can be easily replaced.

Injection Procedures

One common grouting procedure is to drive an open ended rod to the desired depth of grouting; the grout is then injected in stages as the rod is withdrawn. In order to keep the rod open during driving, a loose fitting point or plug is inserted into the open end. Before grouting, the rod is withdrawn several inches to allow the plug to fall out of the rod (or is driven out). The rod is then slowly, but continuously, withdrawn as grout is pumped into the soil. A limitation of the driven rod approach is the potential for short-circuiting around the grout injector as grouting nears the ground surface. This problem may be overcome by using cut-and-fill grouting procedures at these levels.

Another grouting procedure is to use perforated rod sections. In this way, lateral grouting penetration can be achieved without continuous withdrawal of the rod. By attaching perforated rods to non-perforated rods and connecting adjacent rods with a header pipe, the entire zone of several holes can be grouted at once. The rods can be retracted by stages and the upper zone grouted in a similar manner. With perforated rods, penetration of the grout into the soil formation depends upon the particular soil conditions.

Grouting can be completed to any depth using the predrilled hole injection method. Driven grout rods are limited to the upper 7 to 15 m (23 to 49 ft) depending upon the resistance offered by the soil, although grouting rods have been driven or jetted into very loose soils to a depth of 30 m (98 ft).

Typically, injectors are installed vertically because of the ease of construction operations. Angle installation can be performed for both predrilled or driven injectors, depending upon soil formations. Open graded granular soils typically cave in to angle drilled holes; consequently, driven injectors have been found to be more successful for angle grouting. Angle grouting requires an elaborate set-up and a scaffolding-type system to control rod insertion on an angle.

It is anticipated that grouting using the angular direct drive procedure will be limited in depth to a vertical distance of 8 to 9 m (25 to 30 ft). This is due to the difficulties of angular driving, potential deflection by obstacles in the soil, the need to provide as integral a wall as possible and time of construction considerations.

PROJECT APPLICABILITY OF GROUTING

Based upon the literature review and actual grouting experience, it appears that grouting can be a feasible containment method for certain spills in several different soil types. Non-toxic grouts are available. Grouting can be accomplished by relatively simple operations using injection rods driven on an angle into the soil subsurface. Although limited to certain soil types, these grouting procedures can be achieved in a timely manner so that a grout envelope can be completed prior to escape of the contaminant.

The limitations of grouting must also be recognized and taken into consideration when evaluating responses at a specific site. Construction of an impermeable grout barrier requires that the soil to be grouted be permeable to the contaminant. It is possible that the volume of soil contaminated by chemical migration may become excessive if grouting is too time-consuming or is not started immediately. Soils with medium permeability, such as sands and fine silts, are best for grouting as containment. However, it may be desirable to grout in a highly permeable soil if a large amount of chemical remains entrained and can be effectively treated. Where soil types, such as silts and clays, preclude the use of grout (because of their low permeabilities), the contaminant would be held near the spill surface and surface treatment procedures may be the most effective detoxification method.

Another limitation is the difficulty in driving injectors through soil which contains obstacles such as rocks and tree roots. These can deflect an injector. Care must be taken by the system operators to notice occurrences and then place another injection point adjacent to the deflected rods. Finally, the time factor for grouting is critical since the operation can be time-consuming. Preliminary calculations are crucial considering the speed of grouting and predicting, as much as possible, the volume of contaminated soil anticipated over this period. Critical evaluation of all alternative handling options is needed before grouting is begun to preclude the creation of a larger problem than that being solved.

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

SECTION 6

PILOT STUDIES

Pilot tests were performed to evaluate both grout techniques and reaction efficiencies. Two soil types, two reaction systems and two grout types were tested. The main objectives of the pilot testing were:

1. To determine the feasibility of the detoxification procedure on a larger scale
2. To establish critical parameters to aid in system design.

DETOXIFICATION TESTING

Both flow-through and sealed systems were evaluated on a pilot scale. The silica sand that was evaluated in the pilot-scale tests was the same soil that had been tested during flow-through studies and the same Georgia Kaolin clay was used for the sealed tests. Intermediate bulk densities and water contents were chosen to represent average conditions. Redox and precipitation chemical reactions were chosen because they provided a comparison of the impact caused by soluble product and solid precipitate formation. The same contaminant and reactant concentrations were used as those concentrations used in the treatability tests. Two grout types were also evaluated on a pilot level: a chemical and a particulate grout.

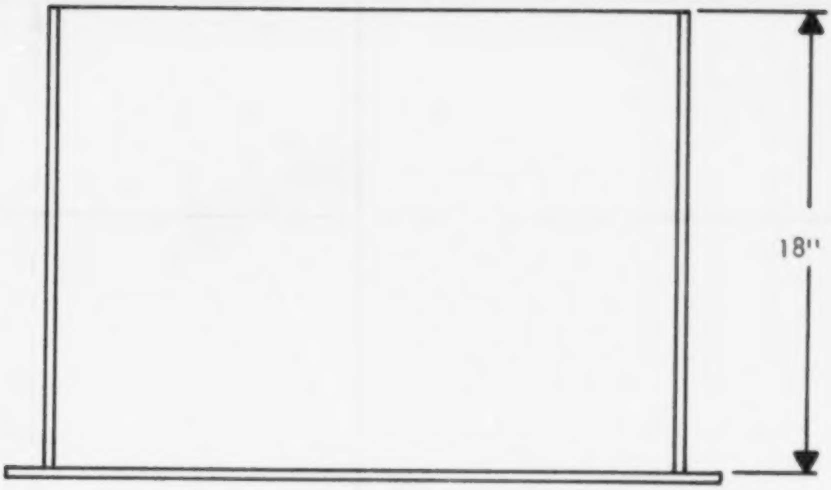
Testing Apparata and Procedures

Special testing cells and procedures were needed in order to conduct the pilot studies. Two plywood boxes coated with epoxy paint, were constructed: a large box for sand testing and a small box for clay testing. The large box was equipped with a plexiglass side that allowed observation of internal flow patterns. For each test procedure, flow-through or sealed, soil and water were mixed, placed in the boxes and compacted in layers to a specified height. The contaminant was evenly distributed over the soil surface and allowed to penetrate underlying soil layers. For sealed tests, the reactant was added 24 hours after the contaminant addition and a 48 hour contact time was allowed. Core samples were then taken at eleven locations in the box and analyzed at three depths (Figure 12).

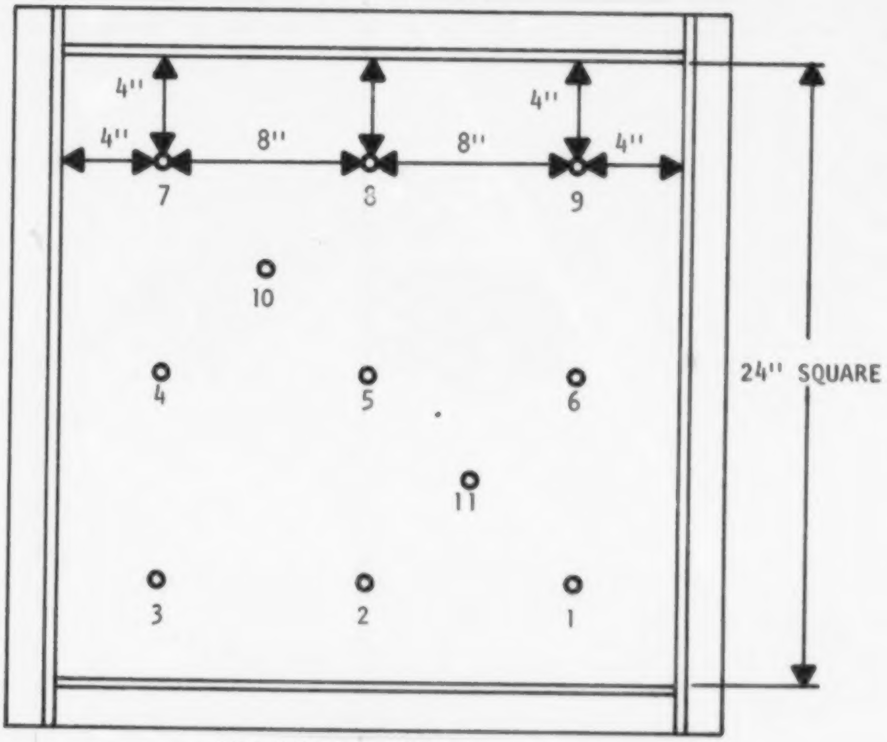
The flow-through testing in sand required additional equipment and time. Various tanks and pumps were assembled (as illustrated in Figure 13). Approximately 2,550 to 2,640 Kg (5,600 to 5,800 lb) of sand were placed

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)



SIDE VIEW OF CLAY BOX


4''
4''
4''
8''
8''
4''
7
8
9
10
4
5
6
11
3
2
1
24'' SQUARE

TOP VIEW OF CLAY
SHOWING SAMPLING LOCATIONS
cm = in. x 2.54

Figure 12. Sealed pilot testing apparata.

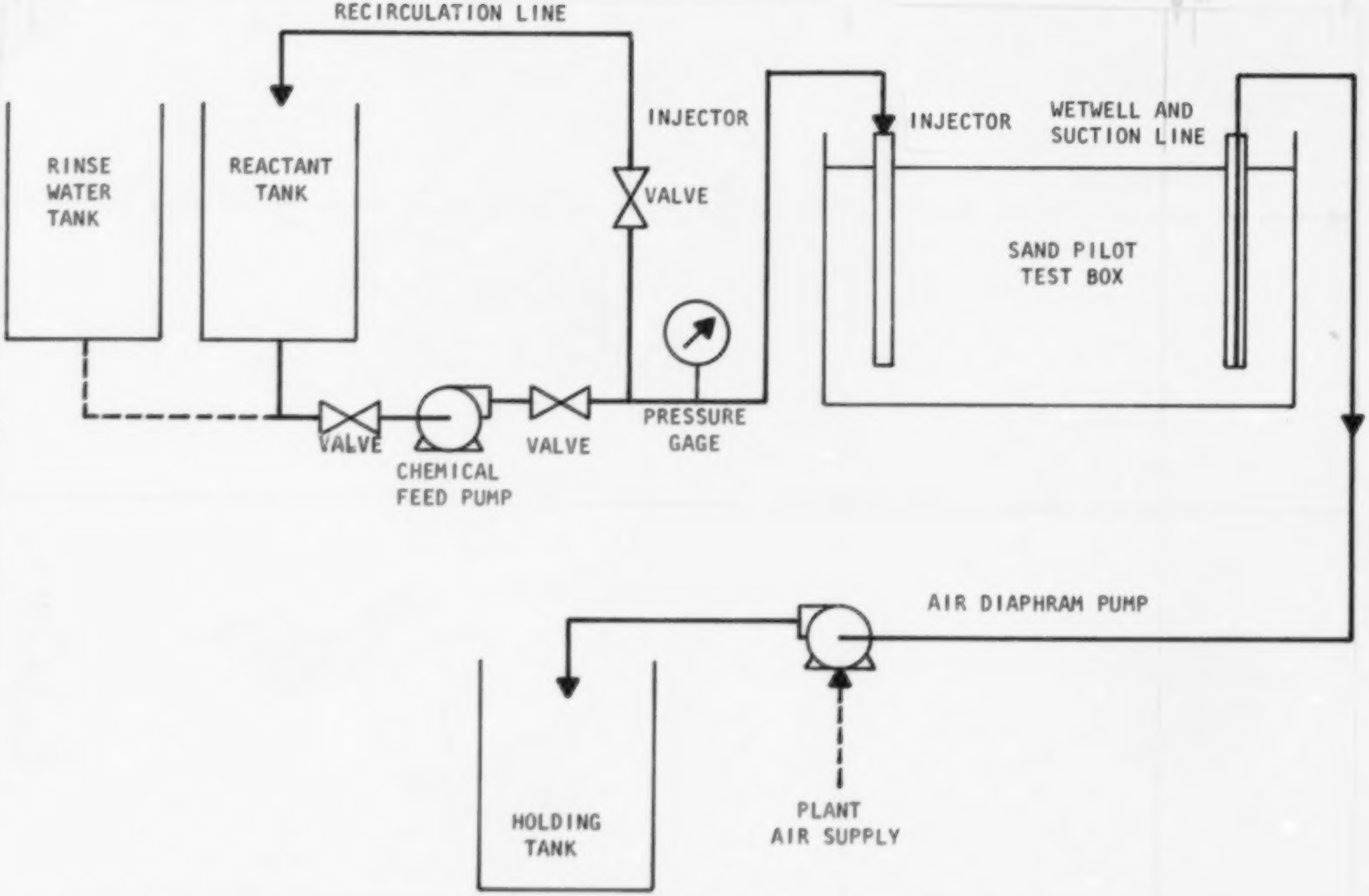

RECIRCULATION LINE
RINSE WATER TANK
REACTANT TANK
INJECTOR
VALVE
VALVE
CHEMICAL FEED PUMP
VALVE
PRESSURE GAGE
INJECTOR
WETWELL AND SUCTION LINE
SAND PILOT TEST BOX
AIR DIAPHRAM PUMP
HOLDING TANK
PLANT AIR SUPPLY

Figure 13. Schematic of flow-through testing layout.

in the box and the contaminant was added to correspond to 25 and 50 percent of the available void volume. After the contaminant had migrated through the soil, an injector and perforated wet well were inserted into the sand. The specified volume of reactant was then pumped through the injector into the surrounding soil, while the excess fluid was pumped from the wet well into a separate holding tank. Rinse water followed reactant addition, after which time core samples were collected at the eleven locations indicated in Figure 14. Three core depths were evaluated.

Results and Discussion of Detoxification Testing

In general, the results from the pilot evaluation were well correlated to those found in the laboratory. (There was an anticipated drop in reaction efficiency but it was not excessive.) As observed in similar pilot studies, the size and geometry of the test boxes impacted the results in a manner that cannot be specifically defined. The pilot tests also provided valuable information that related directly to the final system design and allowed identification of potential operational problems that could be minimized or eliminated by proper design.

Sealed Test Results: Clay--

The pilot-scale sealed or surface treatment test results corresponded closely to those predicted from the laboratory testing. For both sets of clay tests, a contaminant-only test was performed to establish the flow patterns in the clay. As expected, most of the contaminant remained in the upper 10.16 cm (4 in.) of clay with a significant decline in concentration in the lowest 10.16 cm (4 in.) of clay. These results were the basis of the percent removal calculations summarized in Table 11. The redox reactions, associated with the formation of soluble end products, were quite effective, allowing removal of almost all contaminants in the surface layer and most contaminants at lower levels. Precipitation reactions were less efficient, possibly because of void blockage by the insoluble precipitate. For both reaction types, shrinkage cracks, which formed as the surface dried, allowed more effective detoxification in the lower layers. A majority of the contaminant was detoxified in all tests.

Confirmation of the laboratory test results on a pilot level was encouraging. The reactant appeared to follow the path established by the contaminant as it passed through the clay soil. Unreacted pockets of either contaminant or reactant were not detected. Instead, efficient detoxification occurred. As mentioned previously, the main problem with this approach is the void volume available for mixing, contact and reaction. The clay material appeared to adsorb the contaminant and to provide space for the reactant mixing. This phenomenon may merit further study.

Flow-Through Test Results: Sand--

The detoxification effectiveness for the sand pilot tests is summarized in Table 12. The percent removal values were based upon the concentrations of residuals in the soil and represent the combined effectiveness of flushing and reaction. For both types of tests, the most effective

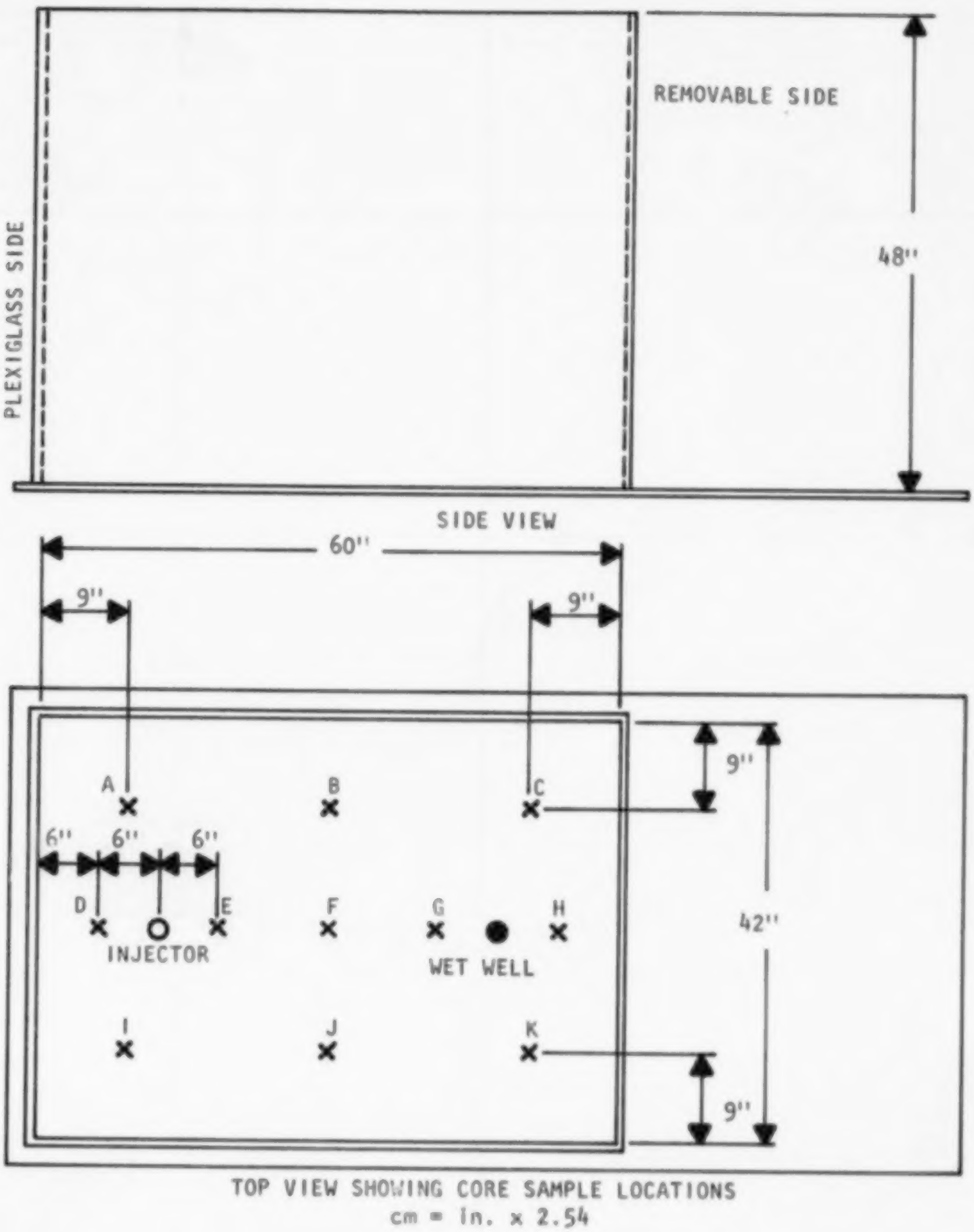

REMOVABLE SIDE
48''
PLEXIGLASS SIDE
SIDE VIEW
60''
9''
9''
A
B
C
9''
6''
6''
6''
D
E
F
G
H
42''
INJECTOR
WET WELL
I
J
K
9''
TOP VIEW SHOWING CORE SAMPLE LOCATIONS
cm = in. x 2.54

Figure 14. Flow-through pilot test box.

TABLE 11. SUMMARY OF SEALED PILOT TEST RESULTS

Test no.	Media	Test conditions		Results			
		Contaminant	% Loading	Core location	Average contaminant concentration, mg/Kg	Average percent removal, total*	
						Cl	
1	Clay	NaOCl	25	Top	10,153	99.6	
	20%			Mid	207	73.6	
	water			Bot.	14	73.8	
						Cl	SO_3
2	Clay	NaOCl	50	Top	20,306	99.9	99.9
	20%			Mid	413	82.3	99.85
	Water			Bot.	28	85.7	99.82
						Cu	
3	Clay	$CuSO_4$	25	Top	4,594	62.1	
	20%			Mid	1,327	99.1	
	water			Bot.	43	57.3	
						Cu	
4	Clay	$CuSO_4$	50	Top	8,197	70.6	
	20%			Mid	2,653	76.0	
	water			Bot.	86	76.8	

$$\text{*\% Removal} = 100\text{x}\ \frac{(\text{concentration of contaminant in soil before treatment} - \text{concentration after treatment})}{\text{concentration of contaminant in soil before treatment}}$$

Note: (a) Treatment for Test Nos. 1 and 2 was redox.
(b) Treatment for Test Nos. 3 and 4 was precipitation.

TABLE 12. SUMMARY OF FLOW THROUGH PILOT TEST RESULTS.

Test no.	Media	Contaminant	% Loading	Core location	Average contaminant concentration, mg/Kg	Average percent* removal**	Average percent removal, injector***
						Cl	SO_3
1	Sand	NaOCl	25	Top	1,411	85	99.78
	5%			Mid	2,066	95.2	99.79
	water			Bot.	3,374	97.6	99.76
						Cl	SO_3
2	Sand	NaOCl	50	Top	2,539	58.3	99.92
	5%			Mid	2,218	100.0	99.90
	water			Bot.	6,606	97.3	99.89
						Cu	Cu
3	Sand	$CuSO_4$	25	Top	1,040	71.5	89.5
	5%			Mid	1,258	89.2	89.7
	water			Bot.	1,262	88.7	88.2
						Cu	Cu
4	Sand	$CuSO_4$	50	Top	2,096	76.7	88.8
	5%			Mid	5,791	94.9	97.9
	water			Bot.	8,580	96.5	97.5

$$\text{*\% Removal} = 100 \times \frac{(\text{concentration of contaminant in soil before treatment} - \text{concentration after treatment})}{\text{concentration of contaminant in soil before treatment}}$$

**Total box = average results for sample locations A through K.

***Removal around injector core sites A, B, D, E, I, J.

Note: (a) Treatment for Test Nos. 1 and 2 was redox.
(b) Treatment for Test Nos. 3 and 4 was precipitation.

detoxification occurred within a radius of 0.45 m (1.5 ft) from the injector. However, detoxification did spread to other areas of the box, as illustrated by the type of chemical residuals remaining after the redox reaction is completed. The core samples collected around the injector contained only a very slight bisulfite residual; the cores in other locations still maintained a chlorine residual. Analyses of the samples also showed that short-circuiting of the reactant directly to the wet well did not occur. As with the laboratory tests, precipitation effectiveness was not as great as that from redox detoxification. Again, this fact is probably caused by the blockage of voids and reaction paths by the solid material. The volume of rinsewater used for these tests was lower than those used in the treatability tests but the results obtained were not detrimentally affected.

During the performance of the pilot tests, we noted that other factors should be taken into account during system operation and when evaluating any results:

1. There was a rapid gravity migration of the contaminant to the bottom of the box. Therefore, the time of response in this type (sand) of soil is critical.

2. a) Large volumes of liquid were removed from the wet wells during the treatment procedure. The need for an efficient, reliable and self-priming wet well pump is important because the waste stream will vary in composition and temperature as the contaminant and excess reactant are forced through the soil. Precipitates will also be formed in the wet well, so the pump must be capable of handling thin slurries. b) However, less water was necessary for proper rinsing than that used in the treatability tests. A value of 100 percent of the void volume rinse fluid was found to be effective.

3. The back pressure associated with increased void loading and increased volume displacement was higher than expected and must be carefully watched during operation. Back pressures up to 550 kN/m^2 (80 psig) were noted so pumps should be designed to withstand these pressures.

4. The injectors must be driven into the ground to reduce the potential for short-circuiting along the sides. Forward flow rates will be significantly decreased at higher void loadings and after a given pumping period.

5. Some problems were encountered with plugging of the multi-holed injector. Although this type of injector can initially provide a much faster forward flow rate, the potential for plugging is greater and must be taken into account in the final evaluation.

GROUTING TESTS

Several grouting conditions were evaluated on a pilot scale. Grouting was performed solely in the flow-through box because only the sandy soil was amenable to grouting. The testing apparata from the detoxification studies were utilized. Two grout types were evaluated--a silicate grout and a bentonite/cement grout. These grouts were chosen for their low toxicity and general suitability for the reduction of fluid flow through the silica sand used in the pilot test.

One of the objectives of the grouting pilot study was to evaluate the general aspects of grouting in a typical sandy soil. Specific considerations included: the evaluation of pumping rates, flow pattern into the soil, set times, short-circuiting around the injectors and ability to inject grout on an angle.

Silicate Grout

A silicate grout utilizing a copper sulfate and sodium bicarbonate reactant to form a gel was selected for use in the pilot study. The grout was selected because of its reported tendency to break down with time (9). A laboratory program was established in order to define the gel time required for the pilot study and to establish guidelines for users of the equipment; the guidelines were to be relative to the sensitivity of gel time versus grout mix formulas. Approximately 150 gel time tests were run, varying the volume and percentage of the sodium silicate and reactant ingredients. The results are graphically presented in the Appendix, Figure A-2. The time of gel formation and set time varies significantly with rather small adjustments in the ingredients. An optimum range of combinations for timely gel formations was generated. Optimum use of the detoxification equipment will require that similar relationships be estbalished for the other types of silicate grouts that may be considered for use; the selection of grout will depend upon the chemical-related problems, such as pH of the spill contaminant.

Gel time is directly related to ambient temperature. It is expected that slight changes in ambient temperature in the field, creating temperatures that were different from the laboratory conditions, may have a significant effect upon the setting time.

Bentonite/Cement Grout

A bentonite/cement grout was used in the neutralization pilot study test. Five different batch formulas of grout were used, varying the amounts of water, bentonite and/or cement. A patented fluidizer supplied by the Intrusion Prepac Company was used to help the grout penetrate into the sand formation. The actual batch formulations are included in the Appendix, Table A-7.

Injector Installation and Pilot Study Testing

Grout injectors, comprised of EW rod, were inserted into the compacted sand. Injectors were inserted at a 45 degree angle into a predrilled auger hole just slightly smaller than the size of the injector. The end of the injector was covered to minimize soil plugging. After the injector was driven into the small, predrilled hole, it was withdrawn slightly to allow for grout flow. Grout pumping was performed, utilizing the previously described pump and tank apparatus (Figure 13). The rates of grout flow and corresponding pressures, as well as observations of flow patterns, were recorded. While grouting operations were in progress, the remainder of the grout batch in the storage tank was observed in order to determine if setting was occurring. Total time elapsed from initiation of batch operations was recorded during each test.

One day after each test, the soil was excavated to check for the presence of grout. After the sodium silicate test was completed, the grout surface was uncovered and a fluorescein dye was added to visually estimate the permeability reduction resulting from the grouting operations. The fluorescein penetrated less than 0.64 cm (0.25 in.) into the grouted soil, indicating that a highly impermeable grouted surface had been formed.

Discussion of Grouting Test Results

The pilot scale testing indicated that both bentonite/cement and silicate grouting were feasible for the sandy soil tested. The silicate grout was easier to pump, i.e., it required lower pressures and had less erratic pumping rates than the bentonite/cement grout.

The silicate grout gel times varied significantly for the pilot study when compared to the laboratory testing for the same grout formula. This indicates that each field mix batch of grout should be carefully observed and should be pumped as quickly as possible.

When the grout injectors were withdrawn and grouting approached the surface, a short-circuiting effect was noted as the grout flowed along the injector pipe and exited at the ground surface. This is not an uncommon occurrence and occurs when the pumping pressure exceeds the effective overburden pressure at the point of grouting. It does, however, significantly affect the groutability of the upper 0 to 0.5 m (0 to 1.6 ft) of the deposit.

Other grout considerations including pumping rates and pressures were observed. These considerations were used to help size equipment for the detoxification unit.

APPLICABILITY TO SYSTEM USE

Pilot studies indicated that soil detoxification was feasible on a larger scale. Both chemical and grout injection were tested and the information

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD, BEGIN SECTIONS HERE

obtained was used to modify design specifications. The design variables that were affected by the results included:

1. The need to drive injectors into the soil
2. The requirement for wet wells that will remove excess liquid from the soil
3. The necessity for pumps to withstand high back pressures.
4. The need for lower volumes of water in the rinse cycle.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

SECTION 7

PROTOTYPE DESIGN, CONSTRUCTION AND TESTING

SYSTEM DESIGN

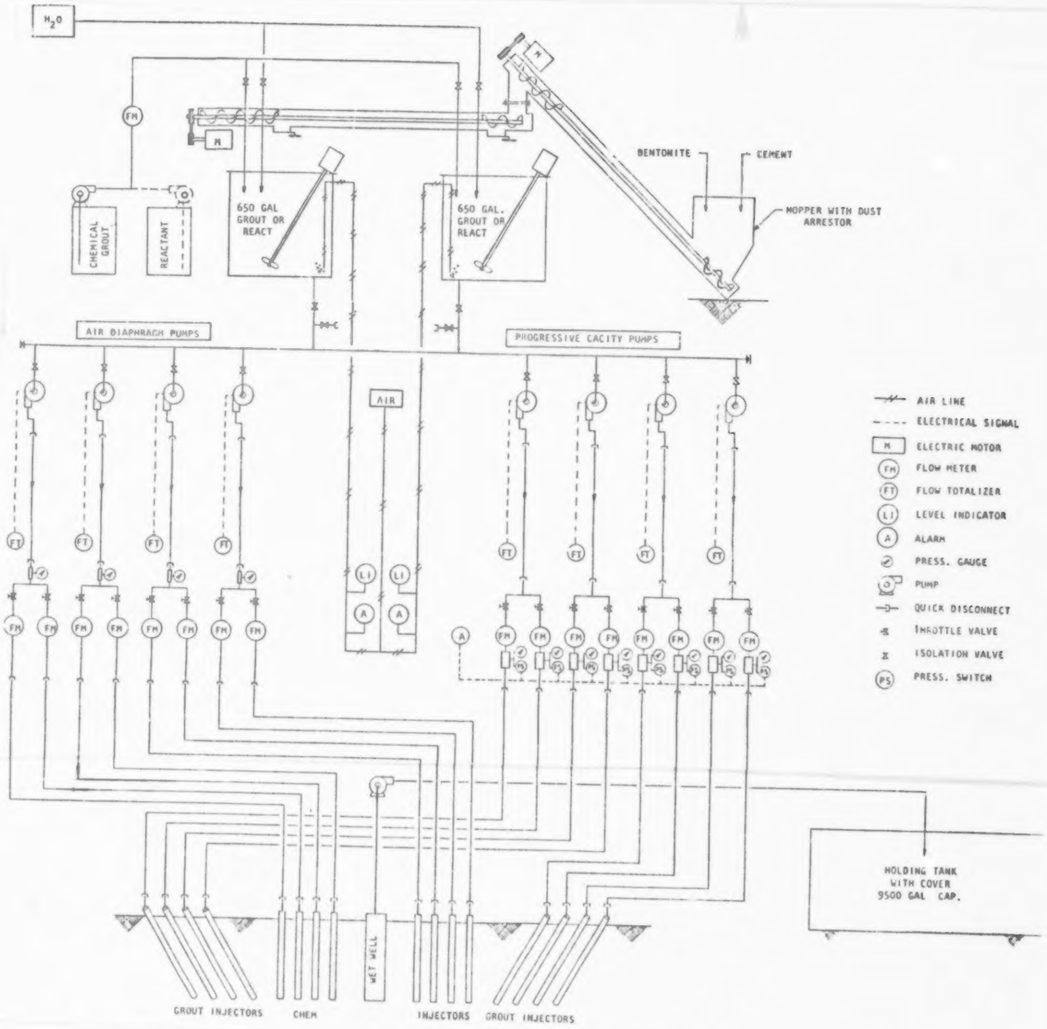
The prototype design was developed after the results of the pilot testing were compiled and evaluated. The first step involved preparation of a process and instrumentation diagram (Figure 15) that included all of the anticipated components of the system in a schematic format. The unit was designed to be as flexible as possible, which will allow the system to remain current with the state-of-the-art of grouting and to be used in a wide variety of situations.

In order to provide this flexibility and to reduce problems of controlling set times for some grout mixes, a batch feed approach formed the basis of the design. This technique involves two feed tanks that can be operated sequentially. It is anticipated that one batch of chemicals or grout will be mixed while the other is being pumped. A solids conveying unit is provided to feed dry chemicals or grout to the top of the tanks. Provisions are also made for manual feed, if it is necessary. Concentrated liquid chemicals can be pumped from bulk chemical barrels to the top of the tanks. Separate process water connections and overflow lines are also included with each tank. Fill lines are equipped with brass, quick disconnect fittings.

Two types of pumps are required to handle abrasive grouts and corrosive chemicals. Four progressive cavity pumps are used for grout injection because they can provide forward flow, that is, nearly independent of back pressure and can handle abrasive particulate grouts. These pumps are not readily available in chemically resistant materials, so Hastelloy C air diaphragm pumps (Wilden Pump & Engineering Company, Colten, California) are used in chemical injection and rinsing.

In order to provide proper control of the grouting and treatment systems, various flow metering devices and pressure gages are included. The flow instrumentation is designed to indicate instantaneous flow rate for each injector and total accumulated flow for each pump. Two types of flow meters are needed, one with chemical resistance and another that is calibrated for the higher viscosity grout. The flow totalizer approach is to use a counting device that is attached to the pump and is calibrated for volume per cycle. Pressure gages are also included for each grout injector and each chemical pump. The forward flow of grout or chemicals is controlled by back pressure (exerted by filling soil voids) and by

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)



H2O
FM
CHEMICAL GROUT
REACTANT
M
650 GAL GROUT OR REACT
650 GAL. GROUT OR REACT
M
BENTONITE
CEMENT
HOPPER WITH DUST ARRESTOR
AIR DIAPHRAGH PUMPS
PROGRESSIVE CACITY PUMPS
AIR
FT
LI
A
FM
PS
HOLDING TANK WITH COVER 9500 GAL CAP.
WET WELL
GROUT INJECTORS
CHEM
INJECTORS
GROUT INJECTORS
AIR LINE
ELECTRICAL SIGNAL
ELECTRIC MOTOR
FLOW METER
FLOW TOTALIZER
LEVEL INDICATOR
ALARM
PRESS. GAUGE
PUMP
QUICK DISCONNECT
THROTTLE VALVE
ISOLATION VALVE
PRESS. SWITCH

Figure 15. Process and instrumentation diagram of prototype unit.

the volume of fluid pumped. A monitor of flow rate is also necessary for correlation to the back pressure.

Each pump is equipped to serve two injectors. In this way, the total accumulated flow can be monitored quite closely and the two pumps can be balanced in a manner to provide consistent equal flow to each line. If necessary, the pumps can each feed only one injector. However, two injectors should be used wherever possible in order to decrease the time needed for grouting or treatment. Hosing is provided with quick disconnect type fittings that will allow much easier field handling. Injectors are also included, along with a manual air hammer driving device, driving platform and hydraulic retractor.

System Specification and Justification

The sizes and ratings of the equipment were critical aspects of the unit's design. Table 13 summarizes the specfications for the major pieces of equipment and the justification for their selection.

Component Evaluations

Each of the major needs on the system could be met by different types of commercial equipment. Whenever more than one product that met the specification was available, competitive bids were requested. These bids were then evaluated, first with regard to process restrictions and then with regard to price and delivery times. A summary of this evaluation is presented in Table 14.

Final System Design

Once bids were received and the components ordered, the final drawings for the unit were prepared. Detailed plans showing mechanical, piping and electrical details were prepared in a separate package. Table 15 includes a list of the major components that were either attached to the trailer or provided separately.

The final layout of the equipment is presented in Figure 16 and pictured in Figure 17. There are several important aspects of the layout that must be mentioned. In order to provide access to the pumps and still allow room for the operator, a grating was located approximately 0.45 m (1.5 ft) above the trailer bed. The grating is easily removed to reach valves as required. This grating is intended to allow the operator easy access to the pumps, control panel, and control valves and gages. It is large enough to accommodate two operators with a minimum of difficulty. Pictures of the operating area are included in Figure 18.

A catwalk is also provided along the side of the trailer (Figure 16 and 17). The catwalk will allow manual access to the top of the tanks for solids feeding and maintenance. There is a ladder to reach the enclosed gooseneck portion of the trailer, which houses the generator and compressor. The

TABLE 13. SYSTEM SPECIFICATIONS AND JUSTIFICATION

Component	Specification	Justification
Trailer	- 43 foot - drop deck type - 55,000 lbs	This type of trailer allows room for higher tanks without exceeding the highway height restrictions. The length was needed to place all of the equipment on the trailer, especially the solids feed system. The total length is also within DOT size requirements. The component weights were calculated and used to establish the total weight requirement.
Tanks	650 gallons Chemically resistant	Space limitations and desirable batch sizes were used to establish the needed tank volume. The tank required a bottom draw off, so it was mounted on legs. This restricted the overall height to 6.5 feet. The trailer width also affected the tank diameter. Contact with grouters indicated that smaller batch sizes (500 gal) were desirable in the field to minimize set-up problems in the tank and to keep spoiled batch disposal volumes lower. The size corresponds to batch times of 20-40 minutes, depending upon the pumping rate and number of injectors being fed. Parallel tanks with batch operation were preferred because of potential operating problems in the field. Chemical resistance was important.
Pumps, grout	Progressive cavity 1-9 gpm at 80 psi (tooled steel)	The pumps were sized to allow feed to two injectors, which provided good control of the injection operation.

(continued)

TABLE 13. (continued)

Component	Specification	Justification
Pumps (continued)		The grout pumps were specified to run from 1-9 gpm at pressures up to 80 psi. The pump can tolerate higher pressures. This flow range was acceptable because grouting is a slow operation. Positive displacement units were purchased because they allow forward flow independent of back pressure. Abrasion resistance was important when handling the particulate grouts, so tooled steel construction was specified.
Pumps, chemical	Air diaphragm 0-20 gpm at 80 psi (Hastelloy C)	Air diaphragm pumps were acceptable for chemical injection because the forward flow rate was not critical. The pumps were specified at 0-20 gpm at back pressures of 80 psi because the chemicals can be added more quickly to the soil than the grout. However, the pumps required Hastelloy C construction to allow needed chemical resistance. The pressure requirement was based on experience of grouting contractors and the pressure obtained in the pilot testing.
Mixers	200 cp Rubber-coated, double propeller impeller $1\frac{1}{2}$ HP motors	The grout viscosity was not estimated to exceed 200 cp based on advice from grouting contractors and the literature. This information, plus tank size, allowed a determination of motor size. The impeller

(continued)

TABLE 13. (continued)

Component	Specification	Justification
Mixers (continued)		was specified with a double propeller to provide mixing in more viscous solutions at different depths.
Conveyor	30 cfh.	A trailer-mounted unit was needed to efficient solids handling. The unit was sized to allow mixing of a batch of chemicals within a 30 minute limitation.
Generator	135 kw diesel-electric muffler 30 gal. fuel tank additional	This unit was specified separately to conform with other EPA spill response equipment. A muffler was included to reduce noise levels. A separate 30 gal diesel fuel tank was also procured and mounted on the trailer.
Air compressor	120 cfm at 100 psi	This size was calculated based on air requirements for the pumps and the air hammer.
Hosing	1 1/2 inch ID 100 psi minimum Neoprene (chemical resistance)	The potential losses were calculated and a velocity of 3 fps was desired to keep the grout from settling in the lines. Back pressure was not to exceed 100 psi to protect personnel. The 50 ft. softwall hose lengths and use of

(continued)

TABLE 13. (continued)

Component	Specification	Justification
Hosing (continued)	50 ft soft wall lengths/quick disconnect fittings 25 ft - hardwall lengths	quick disconnect fittings were chosen to minimize field handling problems. Chemical resistance of Neoprene was acceptable considering the more dilute solutions anticipated in the line. Hardwall hose in 25 ft lengths was included to minimize kinking near the unit and injectors.
Flow totalizers	Counting-type, calibrated in tenths of gallons	Different flow totalizers were considered but cost and potential fouling problems prohibited use of certain types. Counting devices on both the positive displacement and air diaphragm pumps are quite accurate and are of low cost.
Flow meters	Viscosity - 200 cp Chemically resistant 0-5 gpm readings-grout 0-7 gpm reading-chem.	Two types of flow meters were needed; one for the more viscous grout and the other for chemical resistance and a lower viscosity. One flow meter was to be supplied for each injector to allow the needed control.
Injectors	5 foot lengths - 3/4" diam. Heavy duty, black steel pipe threaded and couples	The 5 foot lengths are quite easy to drive from a small platform with the air hammer. The lengths are precoupled for ease of handling. The pipe is heavy enough to withstand driving forces and is easy to replace as needed. The diameter was established by contact with various grouters.

(continued)

TABLE 13. (continued)

Component	Specification	Justification
Wet wells	1 1/2" heavy duty pipe (carbon steel) 5 foot lengths	Wells made of this material are less costly and easy to obtain. The suction line of the air pump should easily fit down the well. The length advantages are the same as the injector.
Retraction device	Special design	This is a hydraulic device to provide the needed force. The unit must be capable of retracting at one foot intervals. The speed of retraction is important when used in a full-scale unit.

m = ft x 0.305
Kg = lb x 0.454
l = gal x 3.785
Kg/cm^2 = psi x 0.0703
m^3 = ft^3 x 0.0283
cm = in. x 2.54

TABLE 14. SYSTEM COMPONENTS
ADVANTAGES/DISADVANTAGES/COMPETITIVE PRICES

System	Component	Advantages	Disadvantages
Solids feed	Screw conveyor	1. Easier feed 2. Safer 3. Less manpower	1. More costly 2. Requires more space
	Platform only	1. Cheaper 2. Requires less space	1. More manpower needed 2. Air pollution problem 3. Difficult to use
	Dry feeder (top mounted)	1. Accurate metering 2. Same as screw conveyor	1. Height problem for road transportation 2. High cost
Grout & chemical pumps	Moyno	1. Durable 2. Proven 3. Smooth operation 4. Flow rate back pressure 5. More applications	1. High cost 2. Not chem. resistant 3. Less range available 4. Long delivery
	Wilden	1. Avail. in Hastelloy C (chem. resistence) 2. Can be used for grout/chemicals 3. Greater range 4. Less cost than Moyno	1. Less control for grout 2. Pulsing may be problem 3. Not proven
	Sandpiper	1. Can be used for grout/chemical 2. Greater range 3. Less cost than Moyno	1. More costly than Wilden 2. Same as Wilden 3. Not available in Hastelloy

(continued)

TABLE 14 (continued)

System	Component	Advantages	Disadvantages
	Gear pumps and piston pumps		1. Can't handle abrasive material
Tanks	Fiberglass	1. Less costly than steel 2. Good chemical resistance	1. Doesn't have strength 2. Can't mount equipment
	Lined steel	1. Can mount equipment on it 2. Sturdier	1. Not as chem. resistant 2. More costly
	Rectangular	1. Less space	1. Costly
	Round	1. Less costly 2. Better mixing 3. Easier to maintain 4. Easier to clean	1. More space
Flow totalizer	In line measurement (turbine meter)	1. Remote readout	1. Fouled by grout 2. Can be more costly
	Magnetic counter on pump	1. Not affected by grout	1. No direct readout 2. Requires calibration
Flow meter	Pitot tube Venturi Orifice	1. Direct readout 2. Accurate	1. Fouled by grout

(continued)

TABLE 14 (continued).

System	Component	Advantages	Disadvantages
	Swing vane type	1. Can handle solids 2. Less costly	1. Readout affected by viscosity
Outside tank	Stave tanks	1. Chem. resistant 2. Designed to be portable 3. Easy to assemble 4. Sturdy	1. Costly 2. Not available in size needed
	Pools	1. Chem. resistant 2. Low cost 3. Readily available	1. More difficult to assemble 2. Less durable
Level measure in tank	Float measure	1. Not adversely affected by grout	1. Discontinuous readout 2. Turbulence disrupts operation 3. Interferes with mixer
	Side scope	1. Visible 2. Less costly	1. Adversely affected by grout
	Bubble tube	1. Easy to clean 2. Not adversely affected by grout	1. More costly 2. Affected by specific gravity
Hosing	Neoprene	1. Less costly	1. Not resistant to all chemicals
	Hypalon	1. Good chemical resistance	1. More costly

(continued)

TABLE 14 (continued)

System	Component	Advantages	Disadvantages
Injectors	E Rod	1. Heavy duty	1. Expensive
	Heavy duty steel pipe	1. Less costly	1. Less strength
Trailer	Flat bed	1. Less costly	1. Less available height
	Drop deck	1. More height available 2. More accessible	1. More costly
Piping	PVC	1. Chemical resistance 2. Easy to modify in field	1. Less strength
	Steel	1. More abrasive resistant 2. Greater strength	1. Chemical resistance low
Air compressor	Rotary	1. Quieter	1. More maintenance
	Reciprocating	1. Less maintenance 2. More available	1. Noisier

TABLE 15. MAJOR COMPONENTS PROCURED FOR SYSTEM

Solids Feed

5 - Conveyor and hopper - 30 ft^3/hr

Grout/Chemical Feed

2 - Lined steel tanks - 650 gallon capacity
4 - Variable speed positive displacement pumps, 0-9 gpm/80 psi
4 - Variable speed Hastelloy C air diaphragm pumps, 0-20 gpm/80 psi
2 - 1 HP mixers with double propeller, rubber coated impellers
8 - Flow totalizers
8 - Chemically resistant flow meters, 0 - gpm
8 - High viscosity flow meters, 0 - 5 gpm
12- Isolator pressure gages,0 - 100 psi
4 - High pressure warning switches
2 - Bubble tube level indicators
1 - Barrel pump, plastic, 0-5 gpm

Injection System

1200' - 1½" ID hosing with quick disconnect fittings
2400' Injectors - heavy duty,black steel pipe 3/4" OD/5ft length
Air hammer drive with accessories
Scaffolding for placement of injectors
Wet wells
1 - Retraction device - hydraulic lift/motor/4 couplers
1 - Auger for sampling/placing wet wells
2 - Air operated wet well pumps

Power and Control

1 - Diesel electric generator - 135 kw max. power
1 - Compressor - 120 cfm at 100 psi
1 - Control panel

Miscellaneous Equipment

1 - Drop deck trailer and bulkhead - 43 feet long/5,000 lbs
Laboratory apparatus

(continued)

TABLE 15. (continued)

Miscellaneous Equipment (cont.)

Soil testing apparatus

Scale

Grating and platforms

---

m = ft x 0.305
l = gal. x 3.785
Kg/m2 = psi x 703.1
$m^3 = ft^3 \times 0.0283$

l/sec = gpm x 0.063
l/sec = ft3 x 0.472
Kg = lb x 0.454

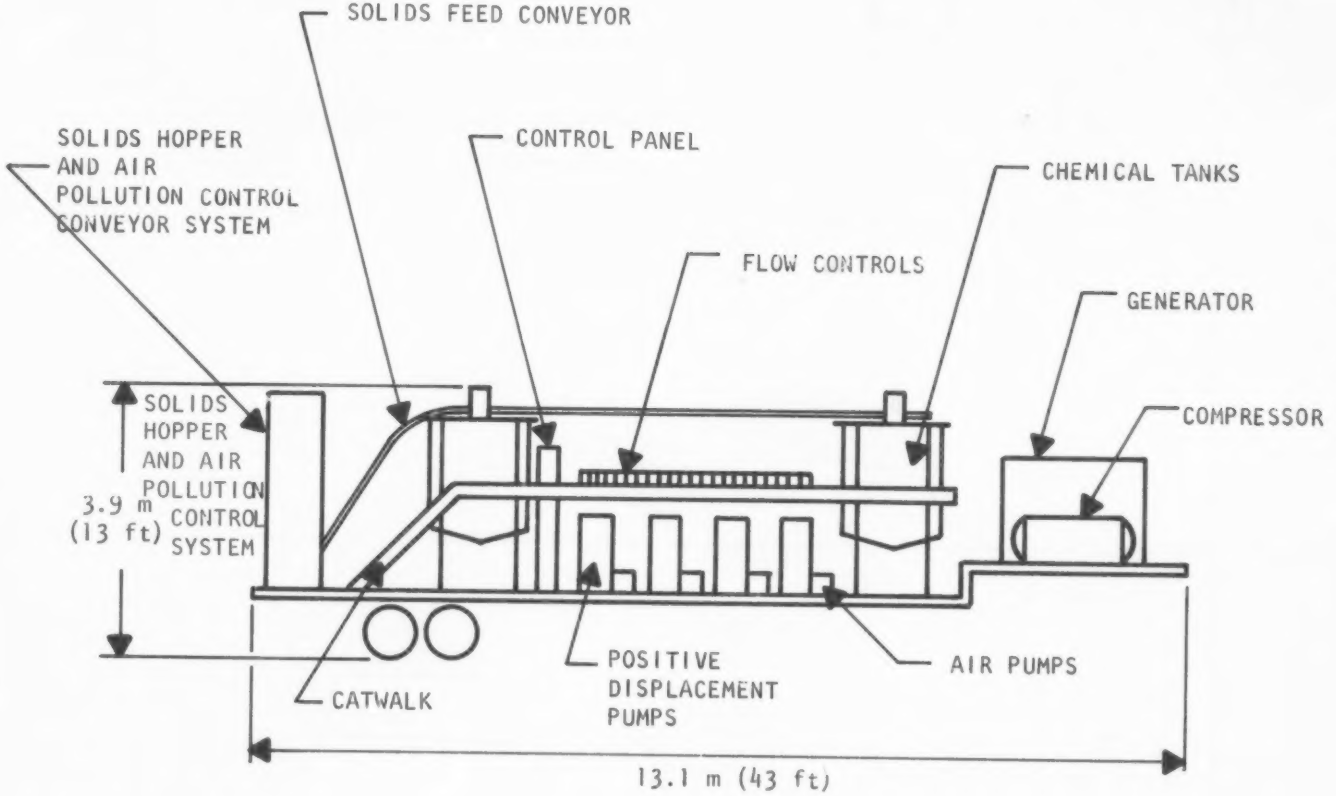
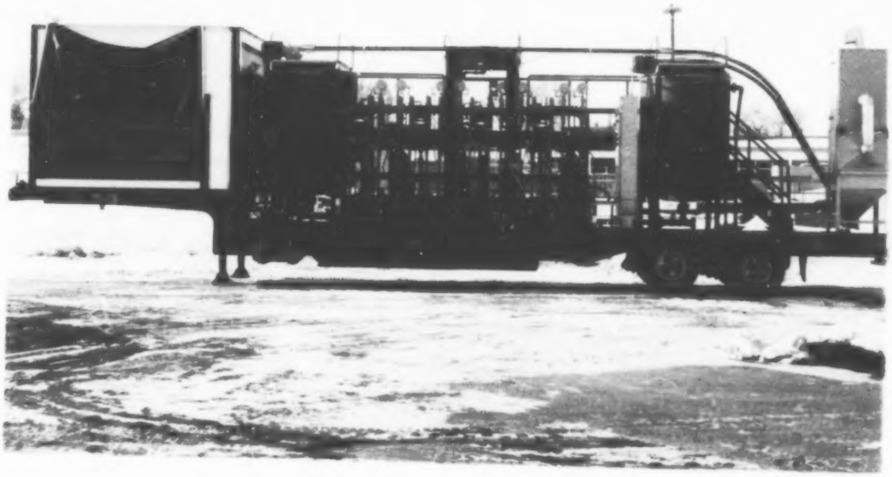

SOLIDS FEED CONVEYOR
SOLIDS HOPPER AND AIR POLLUTION CONTROL CONVEYOR SYSTEM
CONTROL PANEL
CHEMICAL TANKS
FLOW CONTROLS
GENERATOR
COMPRESSOR
SOLIDS HOPPER AND AIR POLLUTION CONTROL SYSTEM
3.9 m (13 ft)
CATWALK
POSITIVE DISPLACEMENT PUMPS
AIR PUMPS
13.1 m (43 ft)

Figure 16. Schematic layout of prototype unit.



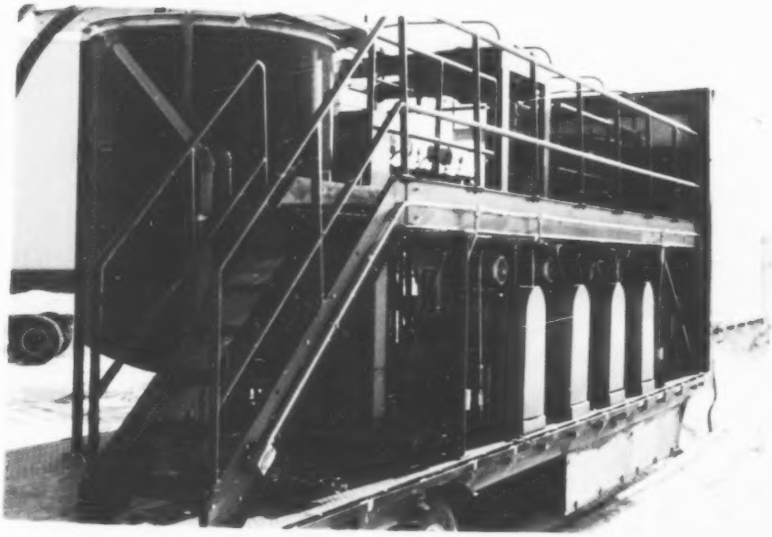


Figure 17. Pictures of in-situ containment/treatment unit.

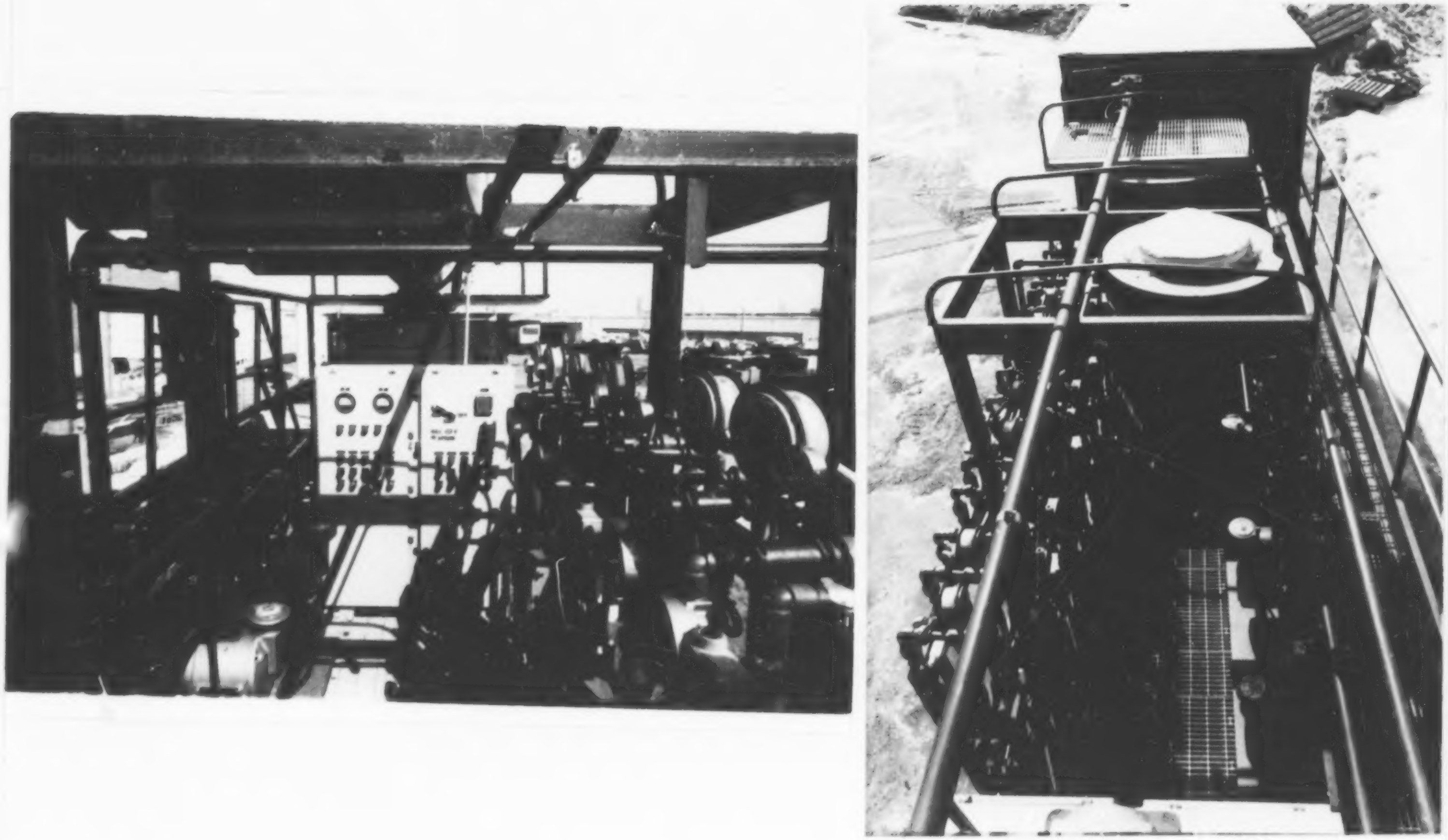


Figure 18. Two views of the operator's area.

covered tanks have grating over the top to allow access to the mixers, solids feed conveyor and the feed chute.

The tanks are positioned at opposite ends of the trailer in order to minimize suction line length to the centrally located pumps. The solids feed hopper is located at the end of the deck with available space in the immediate vicinity to allow some storage of solid chemicals before they are used. Double conveying lines are required to separately feed each tank.

The dust collection device attached to the hopper is a bag collector equipped with its own blower. Because of the potential nuisance and health problems associated with blowing dust or chemicals, the inclusion of this equipment was merited. A fiberglass bulkhead was constructed on the gooseneck of the trailer. An opening is provided in the bulkhead to allow cooling of the generator's radiator and a sliding overhead entrance door is also provided on the bulkhead. A separate canvas cover is included for use during storage of the trailer. This canvas was not designed for use during transportation.

Most of the injection system is separate from the trailer. Storage for the injectors is provided under the trailer floor. The air hammer driving device and the scaffolding can be stored on the trailer or separately, and used as needed. An air hose is provided to operate up to 30.5 m (100 ft) from the unit. A hydraulic gripper type of retraction system has also been included to allow sequential removal of the injectors.

Wet wells for removal of ground fluids are included with two additional air operated diaphram pumps which are to be used for removal of liquid from the wells. Small wells were provided so they could be driven using readily available equipment. The diameter limits their use to non-submersible pumps and therefore pumping depths of approximately 6 m (20 ft). Larger and deeper wells could be utilized with submersible equipment, however, the other functions of the system were not designed to exceed these depths so the increased cost was not felt to be justified. In order to minimize installation problems, the wells can also be cased during placement to hold the soil back. Recommended depths are approximately 0.3 m (1 ft) above the grout barrier. A separate storage stave tank for containment of excess fluid will be provided with the unit by the government during its operation.

CONSTRUCTION AND TESTING

Most of the assembly was performed by contractors with the lowest qualified bids. Separate electrical, mechanical and plumbing contractors were involved. All supervision was provided by Rexnord employees. After the unit was assembled, the individual components were tested for proper operation. Any needed changes were made.

The final testing of the system involved evaluation of its use for in-ground pumping. Both the positive displacement and air diaphragm pumping systems were tested. Injectors were driven into the ground using the air hammer driving device and retracted using a drilling rig. The system worked quite well. The testing re-emphasized the need for careful control of forward flow and back pressure in the pumping system in order to minimize short-circuiting of the grout to the soil surface. A detailed discussion of the testing is included in the Appendix.

SECTION 8

SPECIAL CONSIDERATIONS FOR IMPLEMENTATION

INTRODUCTION

It should be emphasized that not all hazardous chemical spills can be handled using the in-place injection techniques offered by the _in-situ_ containment/treatment vehicle. For example, the use of the vehicle has certain inherent limitations because of the nature of the soils themselves. (These limitations will be discussed in a later portion of this section.) Because of the limitations of the injection and grouting system, this equipment may not be the best solution to a specific problem and this fact must be established as soon as possible.

It appears that the containment/treatment vehicle will be limited to situations with "groutable" soils and treatable spilled contaminants. These situations may not frequently occur. However, it should be noted that serious threats to the groundwater exist mainly in areas where the soil is groutable. For example, if soil permeability is low, the contaminant will not penetrate deeply over time, thus excavation would be more feasible than grouting and in-place treatment. Similarly, if a clay lense that prevents deep grouting exists, it will also contain the contaminant. Therefore, it appears that natural conditions that prevent grouting may also minimize the spill contamination problems. As another example, natural soil attenuation properties can have both positive or negative effects on treatment efficiencies. It must be remembered that once the contaminants are contained, the best treatment option can be identified and the cleanup approach can range from soil washing, to incineration to excavation and hauling. In these instances, treatment may have a separate application, even if grouting is not possible.

In any event, it will be necessary to evaluate the conditions of the emergency spill situation and then to determine if mobilization of the grouting and/or _in-situ_ treatment vehicle is the most cost-effective response for the given problem. (It is anticipated that similar evaluations can be conducted for other equipment in the EPA emergency response "arsenal" so that only the most applicable will be assigned to respond.) Guides for making these decisions are included in this section.

This section will address the various considerations that must be taken into account in order to evaluate the use of the treatment vehicle. A basic scenario is presented; it indicates a "typical" application of the equipment to a hypothetical spill incident. A discussion of the chemicals that can be treated by using in-place techniques is included. The basic limitations of the equipment, with respect to soils and soil chemical interactions, are addressed. Then, a series of decision matrices are developed to guide the user in determining whether in-situ containment and/or treatment are feasible in a specific instance. Possible alternative uses for the vehicle, including use for containment of leaking solid waste disposal sites, is presented.

SPILL SCENARIO

Use of the in-situ detoxification equipment can be demonstrated by a hypothetical spill. This example illustrates a possible response mode for the containment and treatment equipment, following procedures that are described in detail later in this section. The time and chemical amounts required are calculated for the specific situation. Costs for treatment can be determined from this information and compared to costs for excavation and disposal. However, the costs are site and time specific, so detailed economic considerations are not presented in this report.

A typical situation might involve a 37.85 m^3 (10,000 gal) sodium hypochlorite spill along a major highway, such as in the sand dunes of Western Michigan near Lake Michigan. Within two hours of the spill occurrence, the Regional EPA office was notified. Response to a checklist of questions regarding the size, geometry and visual observations of surface soils indicated that the use of the detoxification equipment may be warranted. A competent advance team arrived at the site eight hours after the spill. The team performed field tests that further indicated the applicability of treatment. The mobile in-situ unit was ordered and arrived within twenty-four hours of the spill.

Testing by the advance team served to determine the extent of the spill and the engineering properties of the affected soil. The elevation of the ground water table was estimated; this information, along with the permeability and porosity of the soil, was relevant to the decision about where to curtain the infiltrating spill with a grout curtain. The spill covered an area of 69.6 m^2(750 ft^2) and an estimated volume of approximately 269 m^3 (9,500 ft^3).

Several grouting options were available; the two most probable were grouting with a double ring of injectors or grouting with a single ring of more closely spaced injectors. For either case, the grout injectors would be driven at an angle in order to contain the spill. Since the spill occurred on a fairly permeable sandy soil, a sodium silicate grout was selected. For the double ring injection procedure, the grout required to contain the spill would be nearly 151.4 m^3 (40,000 gal). The single ring injection alternative required half as much grout, indicating that the time needed to grout the spill area would be significantly reduced. While grout effectiveness may be somewhat reduced with the single ring option, it was decided that this option will provide an adequate temporary seal and, because time was the dominant priority, the single ring option was selected for use in this spill situation.

The time required to grout the spill area was dependent on several factors. An injection rate of 0.25 l/sec (4 gal/min) per injector was assumed for the grout. This rate was reduced to an overall average rate of 0.13 l/sec (2 gal/min) because actual grout injection is not performed during the entire day. The in-situ unit is capable of pumping through four injectors at any given time; therefore, the overall average grouting rate was 0.5 l/sec (8 gal/min). A total grouting time of 4.5 days for a single 8-hour shift, 2 days for a double 8-hour shift, or 1.5 days for a triple 8-hour shift was extrapolated.

Once the grout seal was injected and allowed to set, the contaminated soil was rinsed with water and then chemically neutralized. In order to account for the entire volume of a spill of this size, 30 wet well locations were required for chemical injection. The column of water (based on typical sandy soil void characteristics) needed to rinse the spill area was 114 m^3 (30,000 gal). For neutralization, addition of bisulfite at a 2.0 to 1.0 ratio to hypochlorite required 75.7 m^3 (20,000 gal) for treatment. The time required for rinsing and neutralization was 9.7 days for a single 8-hour shift, 4.8 days for a double 8-hour shift and 3.2 days for a triple 8-hour shift.

The general layout for this containment and treatment set-up is presented in Figure 19. The time and materials required are summarized in Table 16.

CHEMICAL TREATABILITY

The treatment method for spilled chemicals depends on both the type of chemical spilled and the soil type that has been contaminated. Not all hazardous chemical spills can be handled using the in-place injection techniques. Many inorganics can be considered for treatment using oxidation/reduction, neutralization or precipitation. On the other hand, certain metal salts should not be handled using in-situ treatment techniques because of their insolubilities in water or low percentage removals that leave highly toxic materials unreacted. Organic compounds may or may not be amenable to treatment, depending upon their solubility in water. Long chain organics and pesticides will probably not be appreciably removed or detoxified using in-situ treatment methods presented in this report because they are quite insoluble in water and are not affected by inorganic reactants. Moreover, other chemicals that react violently with water should not be handled in-situ because of safety constraints.

Treatment Approaches

In the evaluation of treatment techniques, it was found that all systems required injection of a clean water rinse after the reactant was pumped through contaminated soil. In certain circumstances, especially when

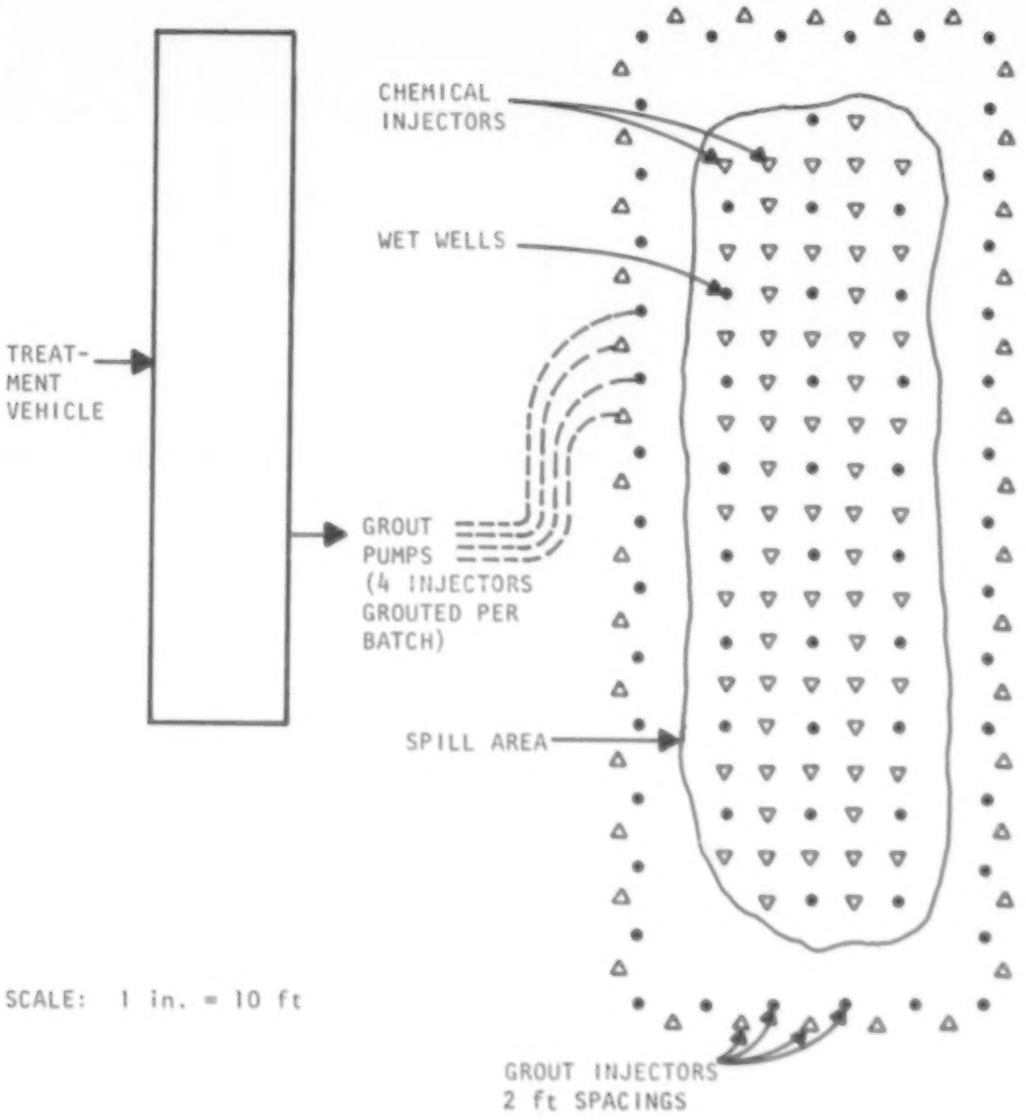

CHEMICAL INJECTORS
WET WELLS
TREAT-MENT VEHICLE
GROUT PUMPS (4 INJECTORS GROUTED PER BATCH)
SPILL AREA
SCALE: 1 in. = 10 ft
GROUT INJECTORS 2 ft SPACINGS

Figure 19. Plan view of grouting set-up and spill area.

TABLE 16. SUMMARY OF TIME AND MATERIAL REQUIREMENTS FOR A HYPOTHETICAL SPILL SITUATION

MATERIALS REQUIRED FOR SINGLE-RING GROUTING

Grout:	20,000 gal sodium silicate grout (15,000 gal water, 3,000 gal silicate, 3,000 lb sodium bicarbonate and 350 lb of copper sulfate)
Grout injectors:	2,000 lineal ft (100 20-ft sections)
Grout hose:	500 ft
Wet wells:	400 ft (30 well locations, 5 to 20 ft sections)
Chemical injectors:	1,500 ft (90 locations, 5 to 20 ft sections)
Note:	l = gal x 3.785 Kg = lb x 0.454 m = ft x 0.305

TIME FOR COMPLETION OF OPERATIONS

0 hr	Spill occurs
2 hr	Regional EPA notified
8 hr	Advance team calls for *in-situ* equipment
26 hr	*In-situ* unit arrives at site
79 hr	Grouting completed by crews working 8-hr shifts
195 hr	Chemical injection and rinsing completed by crews working two 8-hr shifts
205 hr	Observations and check testing indicate that spill has been neutralized
Comparable time for different personnel	
149 hr	For three 8-hr shifts working during grouting and treatment
376 hr	For a single 8-hr shift working during grouting and treatment

dealing with strong acids and bases or other reactive chemicals, a pre-reaction water rinse was desirable. This rinse allowed controlled dilution of the contaminant prior to treatment with a specified reactant. Depending upon the soil and chemical system, a prerinse may also be desirable for removing the contaminants to wet wells for surface treatment. This treatment is desirable for contaminants that are water soluble and that require special conditions of pH prior to effective treatment or for contaminants that form precipitation products, which may resolubilize over time.

Surface soil treatment may require a different approach due to short-circuiting which reduces the treatment efficiencies in upper soil layers. Flooding techniques may be appropriate if the neutralizing agent can be contained over and around the affected area. The approach is similar to that which can be used for fine grained soil systems. An alternative is excavation of these soils for separate disposal or treatment.

Complete treatment is not possible for certain compounds, although partial removal by rinsing may be possible. In some situations, depending upon the contaminant, soil type and spill locations (with regard to population centers), partial treatment may be sufficient. At the very least, partial treatment will reduce the hazard and may allow disposal to a landfill site.

Treatment Methods

In order to allow preliminary identification of a spilled material that may be treated using in-situ techniques, a table (Table A-8, Appendix), which identifies chemicals that may be treatable, has been prepared. Approximately 300 chemicals are listed in alphabetical order and their treatability is classified. Those not treatable and those that are questionable are identified. The questionable category indicates that an expert should be consulted for more information on this chemical before making the final decision. The remaining categories identify treatment methods. A code is presented to number the steps required for each chemical treatment. Generally, if not otherwise precluded, all final treatment should be followed by a clean water rinse if it is felt that a vertical barrier exists or has been attained by grouting. Use of specific acid and basic compounds are presented separately. When another type of chemical is required, this is listed under special treatment. Water rinse alone is used for certain compounds and if water rinse or treatment will result in partial treatment, this is also noted.

These suggested methods have been tested and will vary with different soil types. The techniques have been based on water treatment methods and solubility and are independent of soil type. It is the purpose of the table to provide a screening mechanism for use of the in-situ treatment vehicle. From the data in the table, it will be possible to make an initial determination about contaminant treatability.

EPA-287 (Cin.)
(4-76)

The final choices of treatment methods and reactant types must be made by in-field personnel. In some instances, soil types, for example, may interfere with a suggested treatment approach. Use of certain acidic treatment agents on this soil could cause secondary reaction problems and create excessive chemical demands. It is anticipated that a number of soils could affect in-situ treatment either by exerting a reactant chemical demand or by buffering the impact of the spilled chemicals. These effects and the resultant impact on spill treatment techniques can only be measured in the field.

Grout/Chemical Interactions

There may be interactions between the grout and the chemical that will affect the containment. Care should be taken to choose grouts with properties that will not be affected by the spilled material. This is especially true when silicate grout is used because the integrity of the gel is affected by the pH of the solution. Therefore, it may be necessary to limit containment with silicate grout to circumstances where acids and bases have been spilled or where treatment with an acid/base rinse is suggested. If possible, bentonite/cement should be used instead.

The use of bentonite/cement has few direct limitations because this grout is quite chemically inert and does not require a specified mixture of chemicals to gel. If there is any question about integrity of the grout for the period of spill treatment, a test that involves contact between a grout/soil mixture and contaminated soil can be performed. This test can include placement of a grouted soil layer in a column overlain by a saturated layer of contaminated soil. If necessary to provide contact between layers, the system can be subjected to pressure induced by a water head or compressed air. After a suitable exposure time, established by soil and spill conditions, the column can be disassembled or sampled. Leakage or significant deterioration of the grout layer would indicate that a different grout formulation should be used in the given application. Leakage can be noted and other grout materials can be substituted.

SYSTEM LIMITATIONS

The use of in-situ containment and treatment equipment has certain inherent limitations because of the nature of soils themselves. It is not possible to develop equipment that can effectively function in all situations. This fact has already been illustrated by the previous discussion on chemical treatability. It will be necessary to perform site specific evaluations of the situations to establish if it is cost-effective to treat or contain the spill. Guides for making these decisions are included in this section. The following paragraphs discuss general soil or site characteristics that limit the system's applicability.

EPA-287 (Cin.)
(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD. BEGIN SECTIONS HERE

Soil Grain Size

Grouting is generally limited to granular types of soils that have a pore size large enough to accept grout fluids under pressure. This limitation restricts grouting to coarse silt, sand and gravel-sized soils. The desire to utilize a non-toxic grout rules out some of the more successful chemical grouts and further limits groutability. Coarse sands or gravel, with their high permeability may already have allowed a majority of the spill to flow beyond a groutable depth or horizontal limit; their permeability further restricts the system's use. However, for those soils where grouting may be technically feasible, grouting should also be feasible from a time-to-respond standpoint. Such a standpoint indicates when the soil permeability will be in a range that holds the contaminant until grouting can be completed.

Commonly occurring surficial soil deposits have been mapped for the United States (10). Within the continental United States, about 16 percent of the surface area is comprised of sands and gravel, 21 percent of silts and very fine sands, and 13 percent of clay sand. Many of these soils are potentially groutable, especially the sands and gravel. The potentially groutable soils lie mainly in the midwest, south and southwest. However, the lenses of impermeable soil within a site profile and the water table consideration will also limit use of the equipment.

9-1/8"

Layer Soil Conditions

A soil profile is not generally homogeneous and typically consists of random zones and layers. These zones may or may not be connected in a horizontal or in a vertical direction. Any kind of grouting in a highly layered soil profile may result in incomplete formation of a grout envelope. This is because of the different rate at which grout will flow through the individual soil layers.

Fortunately, grout under pressure tends to flow in the same paths through which the contaminant may flow. However, it should be anticipated that a complete grout envelope will be impossible to construct in all circumstances. For highly critical situations, two or three rows of closely spaced grout injections may be necessary to form as complete a grout envelope as possible within the specific soil profile. Although the containment may not be complete, the grout envelope would be much more effective in minimizing contaminant migration than no barrier at all.

The presence of shallow bedrock may create a layered effect that either restricts or enhances groutability. For example, an open-fissured bedrock surface may allow rapid penetration of a contaminant spill. The equipment developed has not been designed to grout into a bedrock surface unless it can be penetrated by a driven grout injector. Thus,

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

grouting would not be feasible in the open fissured surface. Conversely, some bedrock surfaces are very tight and highly impermeable and would restrict contaminant flow. These surfaces would not require grouting.

Horizontally lying bedrock surfaces can have a beneficial effect. For example, grout injectors would not have to be driven on an angle to contain the contaminant, but could be driven vertically around the spill area. This approach, would enlarge the size and area that could be contained and treated around the spill. The same beneficial condition would exist for near surface clay zones underlying more permeable sands.

Water Table Conditions

The presence of a high water table and rapidly flowing groundwater may hamper or severly limit groutability. A soluble contaminant spilled into a high water table area may mix rapidly with the groundwater, making an evacuation of the contaminant flow path very difficult. Also, the available void space within a saturated soil volume is limited, therefore, the contaminant would tend to spread into a larger area of volume than for an identical spill in a dry soil profile. Again, the estimate of where the contaminant is moving can be difficult.

Where spills occur in an area of rapidly moving groundwater, there is a tendency for the contaminant to enter the ground water stream, flowing much beyond the range of the grout and detoxification equipment. There is some benefit from this dilution effect upon spill attenuation for certain chemicals, but minimal benefits for heavy metals and long chain organics.

The silicate and particulate grouts considered in this project can be diluted by rapidly flowing groundwater thus precluding the formation of a sufficient grout envelope. There are some newly patented chemical grouts developed; these can be set in rapidly moving water. The Japanese grout "Takenaka Aqua-Reactive Chemical Soil Stabilization" (TACSS) is very promising (11). It is reported to be nontoxic and would be suitable for those situations in which silicate grouts could be used. The major drawback is the cost (approximately 10 times greater than typical silicate grouts, 1979 dollars).

Soil Chemical Characteristics

Many of the soil's chemical properties impact the potential effectiveness of *in-situ* treatment of contaminated areas. The direct effects of these characteristics vary with the specific spill situation, so on-site analyses of the situation must be performed before application of a given remedy. The following paragraphs discuss those soil properties that could have a significant impact on treatment.

Buffering Capacity--

The buffering capacity of the soils can affect detoxification for neutralization and, possibly, precipitation reactions. When the soil is strongly buffered, it will affect the amount of neutralization reagent needed. This effect can result in either a significant increase or decrease in reagent amounts, depending upon the soil alkalinity (or acidity) and the type of contaminant involved. The addition of acids into a highly alkaline buffered soil may also result in the formation of more soluble products, which are removed during the rinse process. This removal could result in a complex wastewater mixture, which would require surface treatment.

Adsorptive Capacity--

The physical adsorptive capacity of soils, especially organic soils, can also affect treatment. Certain soils, such as peat or muck, may strongly adsorb non-polar compounds, especially organic chemicals. They react in a manner similar to activated carbon but much less efficiently. These soils will make organic compounds more difficult to remove by rinsing operations.

Cation Exchange Capacity--

Certain soils, especially clays and some silts, have the ability to chemically attract the contaminant in a manner similar to an ion exchange resin. The potential for this type of exchange is indicated by the cation exchange capacity (CEC) of the soil type. The presence of a soil with a high CEC can affect the amount of contaminant (which must be treated) and the amount of reactant required. Spills of metal salts may be attenuated in soils with a high CEC value. Other cations may also be affected.

Mineral Content--

The amount and type of minerals in the soil can impact the use of neutralization and oxidation/reduction treatment techniques. Addition of acids into high mineral content soils can resolubilize metals. Reducing agents can change the ionic form of a precipitated mineral and also cause resolubilization. Resolubilization can increase chemical demand as well as increase the difficulty in treating the wastewater pumped to the surface.

Reduction Capacity--

The anaerobic portions of the soil can exist in a strong reducing state that affects the use of redox treatment. Depending upon the contaminant involved, the reactant amount can be increased or decreased. This impact may be difficult to test on samples removed from the soil mass, but it should be considered when redox reactions are applied.

USER'S DECISION GUIDES

In most instances, it will not be possible to predict the potential for equipment use without detailed knowledge of the site specific variables. Therefore, decision making guides that aid those persons coordinating the response and using the in-situ equipment have been developed. The decisions must be made on several levels. First, a general decision can be reached based upon readily available information that an observer

EPA-287 (Cin.)
(4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

in the field obtains. The decision will involve determining whether or not to dispatch a specially trained advance team to the site. This team would perform in-depth evaluations of soil and chemical conditions to determine if in-situ containment and treatment are possible and/or cost-effective. The team can then relay their technical recommendations to personnel who have authority to dispatch the mobile detoxification vehicle. Additional non-technical considerations, such as local issues and concerns, are required at this point, prior to reaching a final decision.

All decisions must be reached as quickly as possible so that the spill has not migrated past a treatable point by the time the detoxification vehicle reaches the site. The initial approach of using an advance team may appear to be slow, but if all personnel involved are familiar with the decision making steps, then the process can proceed rapidly. The alternative to this evaluation is to make a "go or no go" decision without knowing the facts. This approach could result in costly errors.

Overview of Decision Guide Approach

An overall approach to the determinations that must be made is presented in Figure 20 as a series of decision steps. The initial and final decisions must be made by personnel who are in the position to authorize mobilization of the equipment. The basic considerations establish if in-situ containment and/or treatment would be possible under the best conditions. Availability of equipment and site accessibility can then be evaluated. If treatment does appear possible, an advance team can be sent to further study the situation and to recommend the use or non-use of the equipment, based on site specific testing. A preliminary detoxification approach can be developed and the cost-effectiveness evaluated. Then, an authorized person can compare costs and feasibility to other methods, weigh the impact of warranted non-technical influences, and determine if use of the equipment is warranted. The various components of the decision guide are discussed in the following paragraphs.

1. Determine if Spill is Suitable for Containment/Treatment Using the Equipment

Making this determination will involve receiving information from an on-site observer. The information to be obtained includes:

a. Name and quantity of material spilled
b. Location of spill
c. Soil types in area
    1. Rocky
    2. Sandy
    3. Clayey
d. General topography of the area
    1. Flat
    2. Undulating
    3. Rolling

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

PAGE NUMBER
EPA-287 (Cin.)
(4-76)

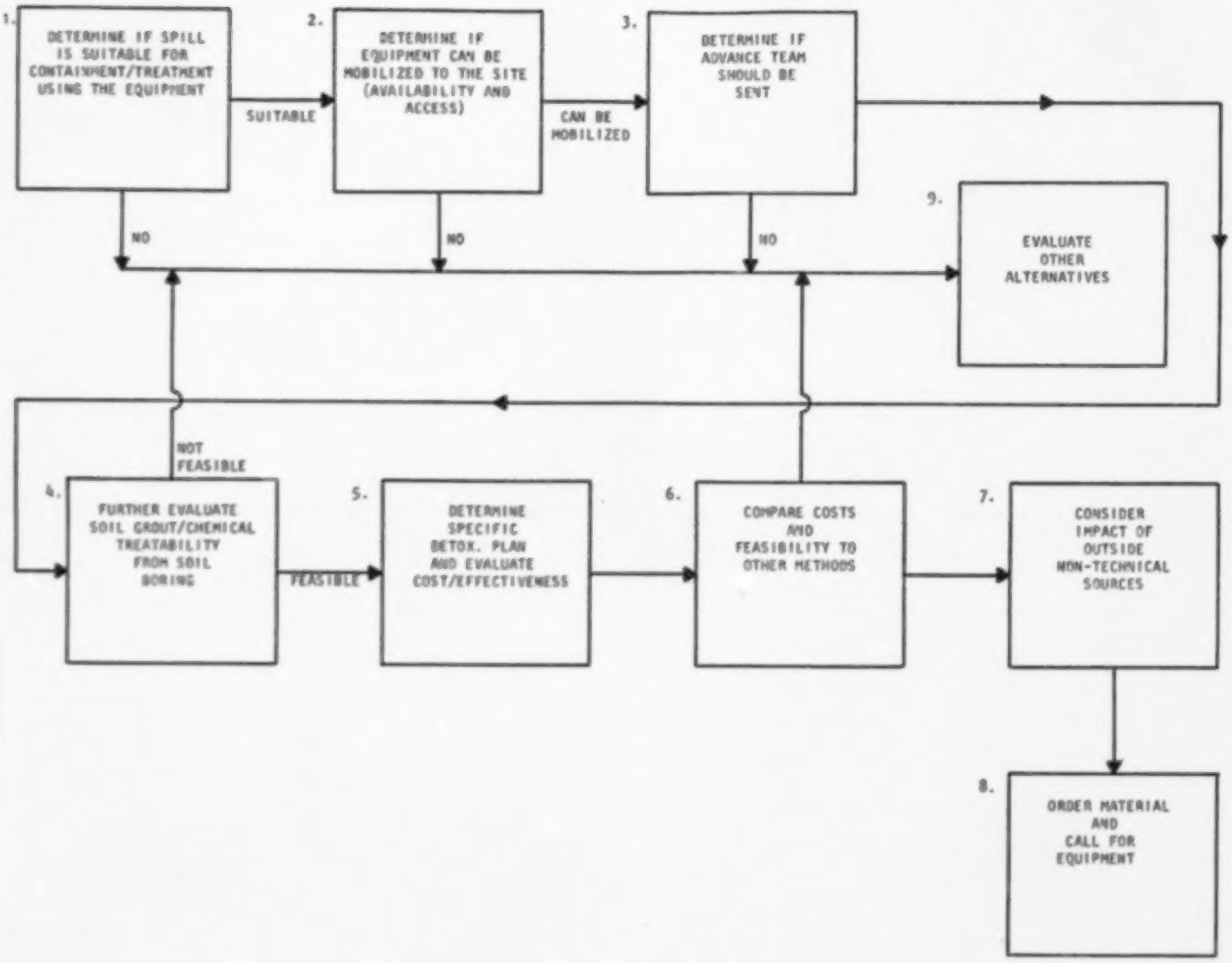

1.
DETERMINE IF SPILL IS SUITABLE FOR CONTAINMENT/TREATMENT USING THE EQUIPMENT
SUITABLE
2.
DETERMINE IF EQUIPMENT CAN BE MOBILIZED TO THE SITE (AVAILABILITY AND ACCESS)
CAN BE MOBILIZED
3.
DETERMINE IF ADVANCE TEAM SHOULD BE SENT
NO
NO
NO
9.
EVALUATE OTHER ALTERNATIVES
NOT FEASIBLE
4.
FURTHER EVALUATE SOIL GROUT/CHEMICAL TREATABILITY FROM SOIL BORING
FEASIBLE
5.
DETERMINE SPECIFIC DETOX. PLAN AND EVALUATE COST/EFFECTIVENESS
6.
COMPARE COSTS AND FEASIBILITY TO OTHER METHODS
7.
CONSIDER IMPACT OF OUTSIDE NON-TECHNICAL SOURCES
8.
ORDER MATERIAL AND CALL FOR EQUIPMENT

Figure 20. Overview of decision making procedures.

        4. Hilly
        5. Mountainous
    e. Condition of spilled material
        1. Solid-laying on soil surface
        2. Liquid-pooling
        3. Liquid-sinking slowly (small pools)
        4. Liquid-soaked into soil
        5. Vapor emitted (in combination with above)
    f. Date and time spill occurred
    g. Amount of surface area affected by the spill
    h. Nearby bodies of water
    i. Weather conditions.

Once this information is obtained, it may be possible to make a preliminary determination about use of the equipment. When the identity of the material is known, the coordinator can check Table A-8, Appendix to determine if the contaminant may be treated or rinsed. The definition of spill quantity is critical in order to determine if treatment is feasible.

Knowledge of location may aid in determining the potential danger of the situation. The coordinator can make a preliminary assessment of groutability by considering visible soil types, topography of the area, the condition of the spilled material and the time elapsed since occurrence of the spill. If the spilled chemical has already disappeared into a rocky or sandy soil, grouting to contain the major portion of the spill may not be possible. However, depending upon the hazard of the chemical, partial treatment may still be feasible.

The size of the affected area should also be considered in the initial evaluation. If only a small area is contaminated, excavation may be a more feasible response than in-situ treatment. The availability of equipment for excavation and the distance to disposal sites must also be considered.

Finally, if possible, it is desirable to estimate ground water location. Nearby surface water or soggy ground may indicate a high ground water table which would preclude use of the equipment.

From this information, the coordinator should be able to judge if further investigation into in-situ treatment or containment is needed. If so, equipment mobilization should be considered. If not, other alternatives should be evaluated.

2. Determine if Equipment can be Mobilized to the Site (Availability and Access)

The coordinator can determine the availability of the equipment by checking with the contractor who operates the response equipment. If the unit is ready for use, then access to the site can be considered. This decision will also involve determining some information from the on-site observer. The information needs include:

a. The distance of the spill from the nearest access point
b. The general terrain of the area
   1. Flat
   2. Rolling
   3. Mountainous
   4. Dry
   5. Swampy

If there is a way to gain access to the site from a nearby road and if the terrain appears capable of supporting the vehicle and auxiliary equipment, then the unit may be usable.

3. Determine if Advance Team Should be Sent

If the conditions at the site appear feasible, then the coordinator can send an advance team to the site to perform more specific testing. The decision should also be based on availability of the team, travel time, and hazards involved.

4. Further Evaluate Soil Grout/Chemical Treatability from Soil Borings

The advance team can then make in-depth on-site tests to establish chemical and soil amenability to containment and treatment.

5. Determine Specific Containment Detoxification Plan and Evaluate Cost Effectiveness

If the advance team determines that containment or detoxification is feasible, they can prepare a specific plan for handling the problem. This plan should include a determination of injector and wet well spacing, calculations of the amounts of grout and treatment material needed and the time for response. A summary of the situation, similar to that presented in Table 16, should be prepared. The team should also provide an estimate of the percent detoxification anticipated for the area. This information can then be submitted to the coordinator, who can make an estimate of the necessity for and cost to treat the spill.

6. Compare Costs and Feasibility to Other Methods

The coordinator can then compare treatment effectiveness and costs using *in-situ* techniques to effectiveness and costs associated with handling the soil using other procedures. These alternatives may include excavation and handling, incineration, soil washing or direct rinsing with no containment. The best alternative can then be identified.

7. Consider Impact of Outside, Non-Technical Issues or Concerns

The recommendation to treat contaminated soil using *in-situ* techniques may be affected by non-technical considerations. These considerations generally involve local or state politics, which are strongly affected by citizen dissent, or the action of environmental groups. The coordinator must weigh each of these considerations before making a final decision.

8. Order Material and Call for Equipment

If the decision is made to use the equipment, it can be ordered and mobilized; initial supplies of grout, chemicals, process water and additional rental equipment should be ordered.

Advance Team Decision Guidelines

After the decision has been made to send the advance team to a spill site, a trained staff of people is involved. The advance team should be comprised of two or three people and a package of soil and chemical testing equipment. The team will perform a variety of tests to determine if grouting or in-situ treatment is feasible. Figure 21 outlines the decisions that must be made by the advance team. A parallel evaluation can be made for grouting and chemical treatment feasibility. Once the applicability of the procedures has been established, then the specific approach should be developed and material requirements should be established.

1. Determine if Equipment can be Mobilized on the Site Terrain

The team can make visual observations about access of the equipment to the spill site. The terrain must be compatible to moving the trailer to within 46 m to 92 m (150 to 300 ft) from the spill site. Space should be available for set-up of the auxiliary tanks or for use of the separate physical/chemical water treatment trailer. Access should be available for delivery of water and chemicals close to the spill site.

2. Estimate Affected Area

The extent of area covered by the spill should be measured by the advance team. The team will have available appropriate safety equipment and can closely approach the spill site. Direct measurements, as well as observations of the site, should be made for use in later calculations.

Steps 3 to 8 and Step 9 to 13 below, can be performed concurrently.

3. Obtain Surface Soil Samples

Surface core samples should be collected in several contaminated areas. All necessary safety procedures should be carefully followed. The core depth should extend to the top 1.5 m (5 ft) or less, depending on the penetration distance of the contaminant. Location of cores should be set by noting differences in soil type or contaminant accumulation.

4. Measure Initial Concentration of Contaminant

The soil cores should then be proportioned into 3 to 5 sections and the

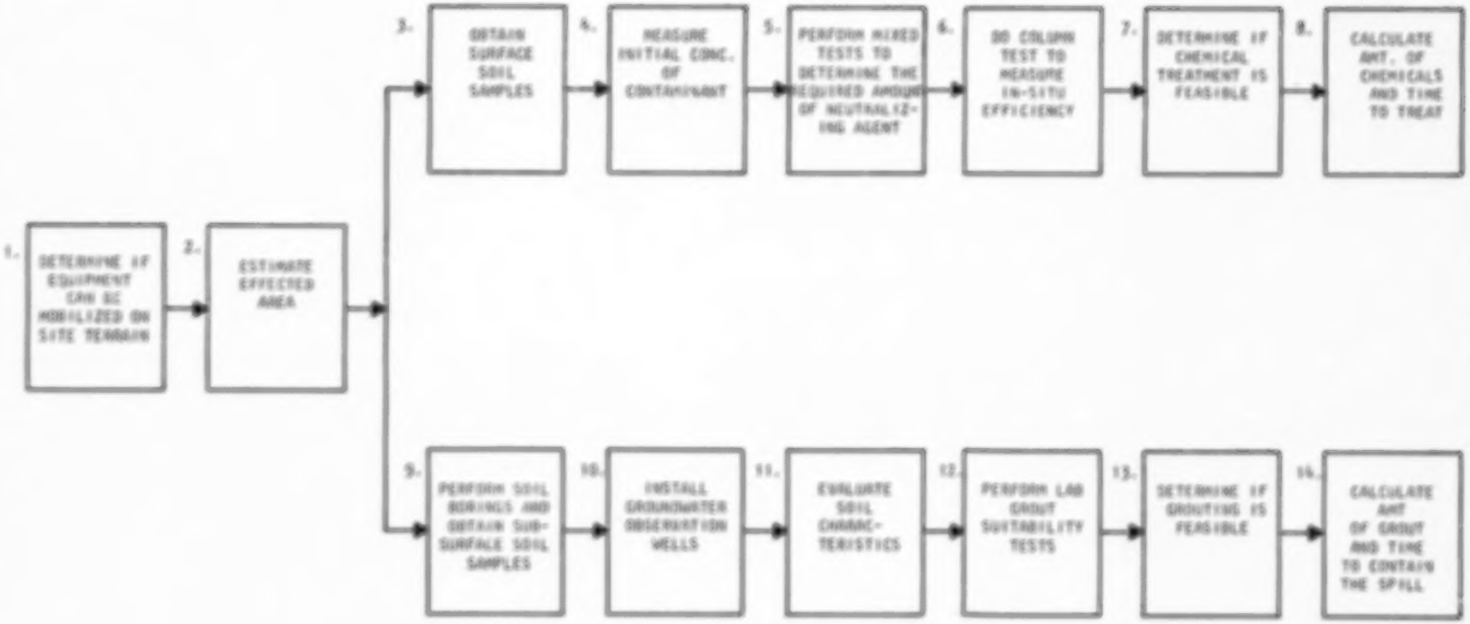

1.
DETERMINE IF EQUIPMENT CAN BE MOBILIZED ON SITE TERRAIN
2.
ESTIMATE EFFECTED AREA
3.
OBTAIN SURFACE SOIL SAMPLES
4.
MEASURE INITIAL CONC. OF CONTAMINANT
5.
PERFORM MIXED TESTS TO DETERMINE THE REQUIRED AMOUNT OF NEUTRALIZING AGENT
6.
DO COLUMN TEST TO MEASURE IN-SITU EFFICIENCY
7.
DETERMINE IF CHEMICAL TREATMENT IS FEASIBLE
8.
CALCULATE AMT. OF CHEMICALS AND TIME TO TREAT
9.
PERFORM SOIL BORINGS AND OBTAIN SUB-SURFACE SOIL SAMPLES
10.
INSTALL GROUNDWATER OBSERVATION WELLS
11.
EVALUATE SOIL CHARACTERISTICS
12.
PERFORM LAB GROUT SUITABILITY TESTS
13.
DETERMINE IF GROUTING IS FEASIBLE
14.
CALCULATE AMT OF GROUT AND TIME TO CONTAIN THE SPILL

Figure 21. Decision guide for advance team.

contaminant concentration should be measured for each section. The soil density and water content should also be measured so that the results, reported in weight of contaminant per weight of dry soil, can be related to the affected area. Depending on the contaminant, analyses can be done in the field, at a local school laboratory or by contracting with a service lab.

5. Perform Mixed Tests to Determine the Required Amount of Neutralizing Agent

The contaminated samples should also be tested, using a completely mixed test. The purpose of the tests will be to approximate the degree of reaction effectiveness and the amount of reactant required to detoxify the contaminant in the soil. After reaction, the soil can be separated from the liquid phase and re-analyzed in order to establish removal efficiency.

6. Perform Column Tests to Measure *In-Situ* Efficiency

Column tests are needed to evaluate the *in-situ* soil removal efficiencies. It is recommended that contaminated soil be packed into a column, flooded with reactant from the surface, rinsed with clean water and then re-analyzed. Liquid drained from the system should be collected and analyzed in order to establish anticipated volumes and concentrations for extrapolation to field use. It may be necessary to perform several column tests if soil types or contaminant concentrations vary significantly.

7. Determine if Chemical Treatment is Feasible

All results must be examined to establish if chemical treatment is technically feasible in a given situation. If chemical treatment does not appear as an attractive approach, further testing is not necessary. Examples of reasons to halt further evaluations include:

a. Low initial concentrations of contaminants because of changes caused by soil
b. Ineffective chemical detoxification measured in the shaker tests
c. Excessive volumes or amounts of reactant required for treatment
d. Excessive heat of reaction generated in column tests
e. Low removal rates in column tests

Other factors, such as local issues and concerns, may also influence the decision making process.

It is difficult to define the efficiency that may be considered acceptable in a given situation. Total detoxification may be the only adequate alternative for certain extremely hazardous or resistant chemicals. By contrast, partial treatment followed by natural attenuation, or excavation and disposal to a landfill may be acceptable. The advance team member evaluating this situation should be in close contact with the technical coordinator because other variables could impact the decision.

8. Calculate Amount of Chemicals and Time to Treat

If the approach appears generally feasible, based on removal efficiencies and volumes of reactants and rinse water needed per unit volume of soil, then the anticipated approach should be defined. A definition of the approach should include expected placement of injectors, wet wells and monitoring wells. The advance team should then calculate the materials needed for treatment, as well as the time it will take to perform the operation.

9. Perform Soil Borings and Obtain Subsurface Soil Samples

Soil samples should be obtained from a minimum of four quadrants surrounding the spill. The intent is to define the soil stratigraphy and obtain samples for further testing. Borings should extend at least 1 m (3.3 ft) below the probable depth of grouting, which would be similar to the maximum estimated depth of contaminant flow. A portable gasoline powered auger unit has been provided with the detoxification unit. Important factors to be evaluated from the soil borings include:

1. Specific soil types and thicknesses of individual zones
2. Relative bulk densities
3. *In-situ* moisture content
4. Presence of a high ground water table

The presence of gravel, sand or coarse silt suggests that grouting may be feasible. Clay may suggest barriers to contaminant flow and may require surface treatment or shallow grouting to contain the spill.

10. Install Groundwater Observation Wells

A minimum of four observation wells should be installed around the spill area. Three wells should be placed in the apparent downstream flow direction (down gradient) and one well upstream (up gradient). The wells can be placed in the previously drilled bore holes if the presence of the contaminant is not evident. The piezometers should be PVC pipe or similar inert material of a sufficient size to allow for water sampling and analysis. The tip elevation should be a minimum of 2 m (6.6 ft) below the maximum estimated depth of contaminant penetration. A granular backfill should be placed around the observation well so that the entire soil profile flow can be monitored. Observation well readings should be taken daily, at a minimum, during grouting and treatment operations, and weekly thereafter until observers are satisfied that no contaminant or reactant remains in the area.

The presence of groundwater will help to define the contaminant flow direction and rate, which will be needed to establish the specific grouting plan. The presence of rapidly moving water will negate common grouting techniques.

11. Evaluate Soil Characteristics

Representative soil samples from each boring location should be tested in an on-site laboratory. Each major soil layer at each boring location should be tested. Major soil layers would include clay, silt, sand and gravel. The following tests should be performed where representative:

1. Soil gradation including hydrometer analysis
2. Natural moisture content
3. Atterberg limits
4. Unit dry weight.

The test results will be used to establish the best type of grout for the specific soil types.

12. Perform Laboratory Grout Suitability Tests

The optimum grout for the type and gradation of soil will be defined. A sample of the chosen grout will be mixed with the soil in order to determine groutability and set times.

13. Determine if Grouting is Feasible

Based upon the results of steps 9 through 12, the field team will be able to evaluate whether grouting is feasible for the soil profile or limited by the type of soil, groundwater or other constraints. The field team will make a recommendation to the coordinator about the feasibility for grouting.

Optimum groutability would occur in soil comprised of a moist, uniform, coarse or medium sand, lying on a flat terrain, and water level below 3 m (10 ft). Poor groutability would be found for soil comprised of clays, open graded granular soils with rapidly flowing groundwater or for a layered silt, sand and clay profile.

14. Calculate Amount of Grout and Time to Contain the Spill

If the preliminary results indicate that grouting is technically feasible, then the anticipated material and time requirements must be estimated. First, a layout of the approach is needed, then the volumes and weights of components can be calculated. Finally, an estimate can be made of the time required to contain the spill.

SPECIAL CONSIDERATIONS FOR DETOXIFICATION EQUIPMENT

Adaptability to Other Emergency Situations

The system described in this report has been designed primarily for use in hazardous material spill response. However, it is extremely flexible and adaptable to changes in the state-of-the-art of grouting or to changes in the problem to be solved. In certain situations, the *in-situ* treatment unit may be better used for contamination conditions that are more stable and that allow time for a thorough evaluation of the problem before implementation of a solution.

The use of the batch mode of operation, flexibility for liquid or solid feed to the tanks, and eight parallel tank attachments have increased the ways in which the unit can be used. Extra generating capacity is available at all times and the air compressor may have additional capacity if the air hammer and air pumps are not operated simultaneously. The chemical feed system (air pumps and piping) is resistant to most chemical attacks and the progressive cavity pumps of mild steel allow abrasive resistance. All pumps are variable speed and can be operated against pressures up to 6.8 atm (100 psi).

One of the most promising applications for this equipment is in the containment of leaking landfill sites and impoundment basins and possibly in the cleaning of soils contaminated from the leaching. In the past, many toxic and hazardous waste disposal operations were semi-controlled but essentially unregulated. This situation has resulted in various industrial sites that have been dumping grounds for waste materials through the years. Although in many cases, uncontrolled disposal of wastes may have been stopped, the residual effects of the abandoned waste disposal operations are likely to remain as contaminants trapped within the absorbed layers of various soil profiles. The holding effect is especially prevalent in the near surface organic layers. Treatment can be effective, as demonstrated in the laboratory testing performed for this project, as well as in other full-scale treatment programs (12). However, the application of a neutralization fluid to the contaminated ground surface may have the effect of spreading the initial contaminant much beyond its original borders. Thus, *in-situ* detoxification has not been a common treatment mechanism.

Forming a grout envelope around a previously known contaminated area should minimize the outward flowing ground water wave front so that detoxification could be performed without further jeopardizing ground water supplies. The grout can be chosen as a more permanent barrier or can be used to provide temporary containment while a permanent solution is being developed. Care should be taken to choose a more permanent grout for this use and to check the potential effect of the leachate on grout integrity.

The nature of the contaminant can complicate the grouting process and in some cases render it invalid. The nature of the contaminant can affect the grout during the grout-setting process, or it may attack a grout barrier which has already been formed. The most important factor is the pH of the soil, water/contaminant environment. Sodium silicate grouting or most chemical reaction grouting processes are pH dependent. Thus, determining the set time would require testing of samples of the actual groundwater/contaminant system and the grout to be used.

Recent unpublished studies have shown that bentonite can be severely affected by an acidic environment such as that developed in a typical landfill leachate. Tests have shown that an acidic environment limits the swelling potential of the bentonite, minimizing its ability to form an impermeable wall.

Cement grouts are not as affected by the pH of the environment and, therefore, may be more adaptable to acidic or basic environments. However, cement grouts can be subject to attack after setting by extremely acidic or basic environments and may deteriorate with time.

In addition to the pH of the system, the chemical nature of the contaminant may affect the grout and the systems' groutability. The contaminant may react with the components of the grout and may not only slow the set time but may severely affect the gel formation. Again, this suggests that on-site testing of the actual grout components and contaminants is necessary to evaluate the potential suitability of a silicate grout system. For many contaminant systems, however, it is likely that a grout barrier could be formed, and would be durable for a time period required to neutralize the contaminant. Long term suitability of this type of barrier system would be questionable when in contact with excessively hostile contaminants.

The available literature on the attack of various chemicals on grouts is limited and it is recommended that additional laboratory studies be performed to further evaluate the suitability of specific grout barrier walls.

Soil away from the actual landfill site, which may also contribute to the long term problem by leaching, may be treatable using a rinse or chemical detoxification technique. If so, a ring of secondary or temporary containment could be installed in this area before treatment.

The in-situ system as designed is quite easily adapted to these circumstances. The only limitation could be in forming an integral bottom seal over a large area without allowing additional contaminant penetration. Lateral movement could be quite easily controlled by placement of vertical walls around a contaminant site. Wall depths could be up to 24.4 to 30.5 m (80 to 100 ft), depending upon the soil characteristics. It may even be possible to grout through a ground water aquifer or saturated soil if the proper grout types and formulations are used. The soil and chemical tests to evaluate the in-situ system use at waste disposal sites are essentially the same as those at hazardous material spills except that the identity of the contaminant may not be initially known or a mixture may be involved. Input from industry or government experts on waste treatability should be obtained. Once the feasibility of grouting or treatment is established, economics must be evaluated. Injector spacing of 0.61 m (2 ft) is acceptable and a double grout ring may be needed for the more permanent applications. Most of the other assumptions previously discussed are still valid in this application.

The same concept could be applied to both municipal and industrial waste landfill operations, which are potentially a much larger source of problems. For example, if a leachate was known to be exiting from a landfill, a grout barrier could be placed around the downstream portions, forcing the leachate to reroute, thus enabling collection and treatment. As a result of the expanded interest in leaching landfill sites, their relatively high numbers across the country and the lack of critical time restrictions in this type of response, the use of the in-situ trailer may be best directed to this application.

Other potential uses for the equipment include:

1. Adding surface containment devices and treating surface spills
2. Injection of nutrients into the soil to enhance biological degradation of spilled or contaminating materials
3. Containment of spilled materials for treatment with other equipment.
4. Solution of other soil contamination situations that are caused by improper past disposal methods.

Adaptability of the Designed Equipment to Changes in the State-of-the-Art

The equipment has been designed for specific immediate spill response using techniques that construct a specific non-toxic, quickly installed grout envelope. Contaminant treatment has been defined by available detoxification methods. Notwithstanding these constraints, the equipment has been designed to be adaptable to state-of-the-art considerations for grouting and chemical treatability. Designing a useful piece of equipment based upon research considerations must include the equipment's potential adaptability to other useful situations. Potential applications to several toxic and hazardous waste disposal problems has been described in the last several paragraphs. The adaptability of the equipment to state-of-the-art grouting and treatment techniques is discussed in the following paragraphs.

Because many cohesive or clay soils cannot be adequately grouted by any equipment, and spills tend to lie on the surface, the equipment was evaluated relative to this type of potential surface cleanup. In concept, if a spill on a clay soil could be contained at the ground surface, the treatability techniques and equipment developed would be useful for detoxifying the contained surface spill. Various methods for containing the spill at the surface are available, such as a mounded earth dike to prevent continued horizontal flow. Also, a foam barrier, rapidly sprayed on the ground surface as the spill is flowing, may be effective. In addition, use of an inflatable balloon-type barrier could be evaluated.

With regard to actual grouting operations, a Japanese grout (TACSS) designed to set in rapidly flowing water has already been discussed in Section 8. Also, several grout injection procedures are much more predictable with regard to forming a complete grout envelope. Promising procedures utilize jetting or pile driving. For example, an operation utilizing an H pile section, driven at overlapping intervals to form a grout slurry wall, has been patented under the trade name of Imperwall (13). This process consists of driving a large H pile section into the soil and pumping a bentonite grout into the void formed as the pile section is withdrawn. By overlapping the flanges of the driven sections, a complete bentonite slurry wall can be formed. This process is time-consuming but could have applications in less time dependent contamination situations.

A potentially more beneficial concept, though not yet totally proven, is a jetted grout wall. In one type of system, which is patented, a series of high pressure nozzles are inserted into the soil and a high pressure grout spray is injected with a knife cutting action into the soil as the injector is withdrawn. This knife jetting action can control flow better than through the lower pressure typical grouting operations can. The Japanese have patented such a process which may have future adaptability to the detoxification equipment (U.S. Patent No. 3,802,203, April 1974). Also, Northwestern University staff* are involved in a similar research-oriented project. The detoxification equipment designed for this project may require slight modifications to be able to generate the high pressure required for this grout jetting operation, however, the batching and mixing equipment for the grouts would not require modification.

It is suggested that the equipment be periodically re-evaluated in order to determine its usefulness, and to consider the modifications required to upgrade the equipment to the current state-of-the-art of grout injection and chemical treatability for toxic and hazardous waste materials. In this way, the maximum cost effectiveness of the project development can be continued.

---

*Personal communication with Department of Civil Engineering, Northwestern University (1979).

REFERENCES

1. Dawson, G. W., Shuckrow, A. J., and Swift, W. H., "Control of Spillage of Hazardous Polluting Substances", Prepared for the Federal Water Quality Administration, Department of the Interior, Washington, DC, November 1, 1970.

2. Rilie, R. J., Methods to Treat, Control and Monitor Spilled Hazardous Materials, EPA-670/2-75-042, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

3. Williams, D. J., Polymer Science and Engineering, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1971.

4. Boundy, R. H., and Boyer, R. F., Styrene--Its Polymers, Copolymers and Derivatives, Part 1, Hafner Publishing Company, New York, 1965.

5. Han, G. E., Kinetics and Mechanisms of Polymerization, Vol. 1, Vinyl Polymerization, Part II, Marcel Dekker, New York, 1969.

6. McCaffery, E. M., Laboratory Preparation for Macromolecular Chemistry, McGraw-Hill Book Company, New York, 1970.

7. Bráua, D., Chirdrau, H., and Keru, W., Techniques of Polymer Syntheses and Characterization, Wiley-Interscience, New York, 1971

8. Herndon, J., and Lenahan, T., Grouting in Soils Volume 1-A, State-of-the Art Report, Volume 2 - Design and Operation Manual, Federal Highway Administration, Office of Research and Development, Report Nos. FHWA-RD-76-26 and FHWA-RD-76-27, Washington, DC, 1976.

9. U.S. Army Office, Chief of Engineers, Chemical Grouting--Engineering and Design, U.S. Government Printing Office, EM-1110-2-3504, Washington, DC, 1970.

10. Woods, K. B., editor, Highway Engineering Handbook, McGraw-Hill, New York, 1960.

11. TJK, Inc., Takenaka Aqua-Reactive Chemical Soil Stabilization System, TJK, Inc., Hollywood, California, 1978.

12. Kastman, K. H., and Zimmerman, R. E., "Cyanide Waste Disposal Site Neutralization", ASCE Specialty Conference on Geotechnical Practice for Disposal of Solid Waste Materials, Ann Arbor, Michigan, June, 1977.

13. Imperpile, Thachor Engineering Company, Chicago, Illinois, 1977.

APPENDIX

TABLE A-1. SUMMARY OF OXIDATION REDUCTION TEST RESULTS

Test no.	Soil type	Bulk density, lb/ft^3	Water content, %	Contam. loading % of voids	Detention time, sec	% Contam. entrained	%Entrained contam. reacted	%Entrained contam. flushed	Total % contam. reacted	Total % reactant reacted	Total % contam. removed*
1	Gravel	94	3	100	68	13.6	95.3	4.7	12.9	95.1	100
2	Gravel	94	3	50	67	24.1	94.5	5.5	22.8	97.4	100
3	Gravel	110	3	100	57	19.3	95.4	4.6	17.7	97.5	100
4	Gravel	110	3	50	51	29.6	89.5	10.5	26.4	96.8	100
5	Sand	98	0	100	328	87.6	25.4	74.6	22.3	60.1	100
6	Sand	98	0	100	211	92.0	20.0	80	18.4	62.7	100
7	Sand	98	0	50	480	100	25.9	74.1	25.9	64.3	100
8	Sand	98	0	50	83	100	44.4	55.6	44.4	64.3	100
9	Sand	106	5	100	246	98.7	25.1	74.9	24.8	63.5	100
10	Sand	106	5	100	95	97.4	32.9	67.1	32.0	52.3	100
11	Sand	106	5	50	437	100	30.7	69.3	30.7	56.8	100
12	Sand	106	5	50	119	100	57.3	42.7	57.3	75.4	100
13	Sand	108	9	100	1647	100	27.7	72.3	27.7	59.2	100
14	Sand	108	9	100	175	99.9	66.5	33.5	66.5	67.5	100
15	Sand	108	9	50	913	100	41.3	58.7	41.3	71.2	100
16	Sand	108	9	50	160	100	56.3	43.7	56.3	85.8	100
17	Silt	81	14	100	69540	99.2	12.1	87.9	12.1	41.7	100
18	Silt	81	14	100	1058	100	22.3	77.0	22.3	22.3	98.5
19	Silt	81	14	50	15257	100	39.3	60.4	39.3	75.2	100
20	Silt	81	14	50	8786	100	91.8	8.2	91.8	99.9	100
21	Silt	90	10	100	975	100	42.6	57.4	42.6	81.0	100
22	Silt	90	10	100	Blew out	100					
23	Silt	90	10	50	17791	100	61.5	38.5	61.5	72.6	100
24	Silt	90	10	50	10418	100	52.9	47.1	52 9	87.0	100
25	Silt	99	14	100	28289	100	63.7	36.3	63.7	87.0	100
26	Silt	99	14	100	480	100	70.8	29.2	70.8	70.9	100
27	Silt	99	14	50	41275	100	90.3	9.7	90.3	99.5	100
28	Silt	99	14	50	29659	100	83.6	16.4	83.6	99.8	100
29	Clay	76.9	20	50	2-4 days	100	99.0	1.0	99	98.9	100
30	Clay	76.9	20	50	3-6 days	100	96.6	3.4	96.6	98.9	100

*Small excess of reactant (sulfite) noted in most cases: Sand and gravel—1 to 2 mg/Kg; silt - 3 to 10 mg/Kg; clay - 60 to 80 mg/Kg

Kg/m^3 = lb/ft^3 x 16.018

TABLE A-2. SUMMARY OF NEUTRALIZATION TEST RESULTS

Test no.	Soil type	Bulk density, lb/ft^3	Water content, %	Contam. loading % of voids	Detention time, sec	% Contam. entrained	%Entrained contam. reacted	%Entrained contam. flushed	Total %contam. reacted	Total% reactant reacted	Total% contam. removed*
31	Gravel	94	3	100	153	16.7	34.8	65.2	5.8	81.7	100
32	Gravel	94	3	50	112	25.3	5.5	94.5	4.1	4.7	100
33	Gravel	110	3	100	1033	15.4	23.8	76.2	3.7	100	100
34	Gravel	110	3	50	1085	24.5	22.3	77.7	5.5	7.3	100
35	Sand	98	0	100	960	71.8	41.1	58.9	29.5	38.8	100
36	Sand	98	0	100	1961	59.1	21.8	78.2	12.9	33.9	100
37	Sand	98	0	50	760	100	51.5	48.5	51.5	10.9	100
38	Sand	98	0	50	396	100	32.3	67.7	32.3	25.8	100
39	Sand	106	5	100	6270	78.3	28.3	71.7	22.2	51.4	100
40	Sand	106	5	100	5826	69.4	17.4	82.7	12.1	13.1	100
41	Sand	106	5	50	5848	100	52.2	47.8	52.2	45.8	100
42	Sand	106	5	50	3878	100	10.1	89.9	10.1	50.2	100
43	Sand	108	9	100	3670	91.7	23.5	76.5	21.6	91.7	100
44	Sand	108	9	100	4208	97.4	15.8	84.2	15.3	47.8	100
45	Sand	108	9	50	1083	100	5.2	94.8	5.2	84.8	100
46	Sand	108	9	50	3756	100	3.4	96.6	3.4	81.7	100
47	Silt	81	14	100	87960	100	41.5	58.5	41.5	62.2	99.99
48	Silt	81	14	100	15780	100	33.7	66.3	33.7	25.8	99.99
49	Silt	81	14	50	89220	100	38.0	62.0	38.0	28.8	99.99
50	Silt	81	14	50	89220	100	51.1	48.9	51.1	57.5	99.99
51	Silt	90	10	100	100800	100	30.3	69.7	30.3	32.8	99.99
52	Silt	90	10	100	20460	100	44.0	56.0	44.0	20.4	99.99
53	Silt	90	10	50	89700	100	87.6	12.4	87.6	43.8	99.99
54	Silt	90	10	50	15240	100	50.3	49.7	50.3	24.3	99.99
55	Silt	96	14	100	86403	100	73.6	26.4	73.6	37.8	99.99
56	Silt	99	14	100	80940	100	73.0	27.0	73.0	97.5	99.99
57	Silt	99	14	50	102240	100	99.9	0.1	99.9	2.9	99.99
58	Silt	99	14	50	20940	100	69.8	30.2	69.8	65.7	99.99

*Small amount of alkalinity remained in the soil: sand and gravel—1 to 20 mg/Kg; silt - 1 to 40 mg/Kg

Kg/m^3 = lb/ft^3 × 16.018

TABLE A-3. SUMMARY OF PRECIPITATION TEST RESULTS

Test no.	Soil type	Bulk density, lb/ft^3	Water content, %	Contam. loading % of voids	Detention time,		% Contam. entrained	% Entrained contam. reacted	% Entrained contam. flushed	Total % contam. reacted	Total % reactant reacted	Total % of contam.[a] removed
					sec	pressure used, psi						
59	Gravel	94	3	100	90		12.8	99.7	0.3	12.8	98.9	99.9
60	Gravel	94	3	50	137		22.9	98.2	1.8	22.5	99.9	99.5
61	Gravel	110	3	100	182		14.4	96.3	37.0	13.9	99.4	99.6
62	Gravel	110	3	50			31.3	99.9	0.1	31.3	90.4	99.9
63	Sand	98	0	100	442	0	95.1	36.1	63.9	34.3	39.8	99.9
64	Sand	98	0	100	120	1	93.3	29.6	70.4	27.6	41.0	99.9
65	Sand	98	0	50	346	0	100	85.5	14.5	85.5	42.5	99.9
66	Sand	98	0	50	188	1	100	36.8	63.2	36.2	65.5	99.9
67	Sand	106	5	100	124		98.6	19.5	80.5	19.2	56.3	99.9
68	Sand	106	5	100	738		99.3	26.3	73.7	26.1	36.2	99.9
69	Sand	106	5	50	69		100	33.0	67.0	33.0	80.7	99.9
70	Sand	106	5	50	360		100	44.4	55.6	44.4	44.4	99.9
71	Sand	108	9	100		0	99.9	26.2	73.8	25.8	51.4	99.9
72	Sand	108	9	100		1	100	85.4	14.6	85.4	44.2	99.9
73	Sand	108	9	50	137		99.9	28.3	71.7	38.6	81.9	99.9
74	Sand	108	9	50		10	100	55.6	44.4	55.6	65.4	99.9
75	Silt	81	14	100		5	100	52.3	47.6	52.3	69.3	99.8
76	Silt	81	14	100		10	96.0	45.8	54.2	43.9	50.7	99.8
77	Silt	81	14	50		5	100	94.5	5.5	94.5	96.8	99.7
78	Silt	81	14	50		10	100	99.2	0.8	98.7	94.1	99.6
79	Silt	90	10	100	250,000	5	100	92.3	7.7	92.3	97.9	99.9
80	Silt	90	10	100		10	100	42.1	57.9	42.1	49.2	99.8
81	Silt	90	10	50		5	100	64.7	35.8	64.7	79.5	99.6
82	Silt	90	10	50		10	100	74.3	25.7	74.3	78.0	99.8
83	Silt	99	14	100		5	100	57.1	42.9	57.1	63.8	99.0
84	Silt	99	14	100		10	100	57.7	42.3	57.7	86.7	99.7
85	Silt	99	14	50		5	100	97.8	2.2	97.8	97.2	99.8
86	Silt	99	14	50		10	100	90.0	10.0	90.0	93.0	99.8

[a] Residual contaminant concentrations ranged from: gravel-0.8 to 5.2 mg/Kg; sand 0.2 to 1.5 mg/Kg and silt 5 to 41 mg/Kg.

Kg/m^3 = lb/ft^3 x 16.018

TABLE A-4. SUMMARY OF SEALED REDOX TESTS

Run no.	Soil type	Bulk density, lb/ft^3	Water content, %	Contam. loading % of voids	Time of reaction, hrs	% Contam. reacted	% Contam. residual	% Reactant reacted	% Reactant residual
87	Sand	106	5	50	24	95.5	4.5	39.5	60.5
88	Sand	106	5	50	72	78.5	21.7	77.4	22.6
89	Sand	106	13	50	144	73.6	26.4	76.5	7.6
90	Silt	90	18	50	144	89.0	11.0	88.0	12.0
91	Silt	90	10	25	24	98.6	1.4	98.3	1.7
92	Clay	85.3	20	75	72	98.1	1.9	99.8	0.2
93	Clay	85.3	20	75	144	98.3	1.7	96.0	4.0
94	Clay	76.9	20	75	72	99.5	0.5	99.5	0.5
95	Clay	76.9	20	75	144	96.2	3.8	97.4	2.6

Kg/m^3 = lb/ft^3 x 16.018

TABLE A-5. SUMMARY OF SEALED NEUTRALIZATION TESTS

Test no.	Soil type	Bulk density, lb/ft^3	Water content, %	Contam. loading % of voids	Time of reaction, hours	% Contam. reacted	% Contam. residual	% Reactant reacted
96	Silt	90	10	15	48	79.5	20.5	97.8
97	Silt	90	10	25	48	9.4	90.6	78.3
98	Clay	79.6	20	25	48	74.6	25.4	100
99	Clay	85.3	20	50	48	78.0	22.0	100

Kg/m^3 = lb/ft^3 x 16.018

TABLE A-6. SUMMARY OF SEALED PRECIPITATION TESTS

Run no.	Soil type	Bulk density, lb/ft^3	Water content	Contam. loading % of voids	Time of reaction, hours	% Contam. reacted	% Contam. residual	% Reactant reacted	%Reactant residual
100	Sand	106	5	25	48	78.3	21.7	100	-
101	Sand	106	13	25	48	97.6	2.4	98.4	1.6
102	Sand	106	5	50	48	78.0	22.0	93.1	6.9
103	Sand	106	13	50	48	99.7	0.3	77.7	22.3
104	Silt	90	18	50	48	75.6	24.4	98.2	1.8
105	Silt	90	18	25	48	58.0	42.0	99.8	0.2
106	Silt	90	10	50	48	38.3	61.7	91.0	9.0
107	Silt	90	10	25	48	35.1	64.9	100	0
108	Clay	79.6	20	25	48	82.2	17.8	100	0
109	Clay	79.6	20	50	48	56.5	43.5	100	0
110	Clay	85.3	20	75	48	72.5	27.5	100	0
111	Clay	85.3	20	50	48	87.0	13.0	100	0

$Kg/m^3 = lb/ft^3 \times 16.018$

TABLE A-7. MIX DESIGN - PILOT STUDY TESTING PROGRAM

Batch no.	Batch portion	Design proportions
1	Part A	
	Water - 21.15 gallons	42.3% (by volume)
	Sodium silicate, 7.85 gallons	15.7% (by volume)
	Part B	
	Water - 21.0 gallons	42.0% (by volume)
	Sodium bicarbonate, 8.75 lb	17.5 lb/100 gallons
	Copper sulfate, 0.95 lb	1.90 lb/100 gallons
2	Part A	
	Water, 21.15 gallons	42.3% (by volume)
	Sodium silicate, 7.85 gallons	15.7% (by volume)
	Part B	
	Water - 21.0 gallons	42.0% (by volume)
	Sodium bicarbonate, 7.94 lb	15.88 lb/100 gallons
	Copper sulfate, 1.00 lb	2.00/100 gallons
		(percent by weight)
3	Water, 45 gallons	89.1
	Bentonite, 29 lb	6.9
	Cement, 17 lb	4.0
4	Water, 52 gallons	91.3
	Bentonite, 26 lb	5.5
	Cement, 15 lb	3.2
5	Water, 45 gallons	95.7
	Cement, 17 lb	4.3
	Fluidizer, 0.9 lb	0.0025
6	Water, 24 gallons	89.3
	Cement, 24 lb	10.7
	Fluidizer, 0.5 lb	0.0022
7	Water, 9 gallons	70.2
	Cement, 32 lb	29.8
	Fluidizer, 0.4 lb	0.0037

l = gal x 3.785
Kg = lb x 0.454

TABLE A-8. POTENTIAL TREATMENT PROCEDURES FOR CONTAMINATED SOILS

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Acetaldehyde		x					
Acetic Acid				2. NaOH,dil.		1.	
Acetic Anhydride				2. NaOH,dil.		1.	
Acetone Cyanohydrin	x						
Acetyl Bromide		x					
Acetyl Chloride				2. NaOH,dil.		1.	
Acrolein	x						
Acrylonitrile	x						
Adipontrile	x						
Aldrin	x						
Allyl Alcohol		x				1.	
Aluminum Sulfate		x					
Ammonia			2. HCl,Dil.			1.	
Ammonium Acetate			2. HCl,Dil.			1.	
Ammonium Benzoate		x					
Ammonium Bicarbonate			2. HCl,Dil			1.	
Ammonium Bisulfate						1.	
Ammonium Bromide		x					
Ammonium Carbanate	x						
Ammonium Carbonate			2. HCl,Dil.			1.	
Ammonium Chloride						1.	
Ammonium Citrate						1.	
Ammonium Fluoroborate	x						
Ammonium Hydroxide			2. HCl,Dil.			1.	
Ammonium Hydrophosphine	x						
Ammonium Iodine						1.	

(continued)

Note: Numbers (1,2,3) represent the order of the treatment steps required. All final treatment should be followed by a clean water rinse.

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Ammonium Nitrate						1.	
Ammonium Oxalate			2. HCl,Dil.			1.	
Ammonium Pentaborate		x					
Ammonium Persulfate						1.	
Ammonium Silicofluoride	x						
Ammonium Tartrate			2. HCl,Dil.			1.	
Ammonium Thiocyanate						1.	
Ammonium Thiosulfate						1.	
Ammonium Sulfamate						1.	
Ammonium Sulfate						1.	
Ammonium Sulfide					1.	3.	2.Oxidize^{w}/HOCl
Ammonium Sulfite					1.	3.	2.Oxidize^{w}/HOCl
Amyl Acetate	x						
Aniline	x						
Antimony Pentachloride	x						
Antimony Pot. Tartate	x						
Antimony Tribromide	x						
Antimony Trichloride	x						
Antimony Trifluoride						1.	
Antimony Trioxide	x						
Arsenic Acid						1.	
Arsenic Disulfide	x						
Potassium Arsenate	x						
Potassium Arsenite	x						
Sodium Arsenate	x						

(continued)

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Benzene	x						
Benzoic Acid				2. $NaHCO_3$,Dil.		1.	
Benzonitrile	x						
Arsenic Pentoxide					1.		
Arsenic Trichloride				2. $Ca(OH)_2$, Dil.	1.	3.	
Arsenic Trioxide	x						
Arsenic Trisulfide	x						
Calcium Arsenate	x						
Calcium Arsenite	x						
Benzoyl Chloride	x						
Benzyl Chloride	x						
Beryllium Chloride						1.	
Beryllium Fluoride						1.	
Beryllium Nitrate						1.	
Brucine	x						
Butyl Acetate	x						
Butylamine						1.	
Butyric Acid		x					
Cadmium Acetate					1.		
Cadmium Bromide					1.		
Cadmium Chloride					1.		
Calcium Carbide	x						
Calcium Hydroxide				2. Na_2CO_3,Dil.		1.	
Calcium Hypochlorite						1.	2. $NaHSO_3$,Dil
Calcium Oxide				2. Na_2CO_3,Dil.		1.	
Captan	x						

(continued)

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Carbaryl	x						
Carbon Disulfide	x						
Chlordane	x			1. NaOH, Dil.			Na Bisulfite
Chlorine							
Chlorobensene	x						
Chloroform	x						
Chlorosulfonic Acid	x					1.	
Ammonium Bichromate						1.	
Ammonium Chromate						1.	
Calcium Chromate			2. HCl,Dil.				
Chromic Acetate	x				1.		
Chromic Acid					1.		
Chromic Sulfate					1.		
Chromous Chloride							
Chromyl Chloride	x				1.		
Lithium Bichromate			2. HCl,Dil.		1.		
Lithium Chromate					1.		
Potassium Bichromate					1.		
Potassium Chromate					1.		
Sodium Bichromate					1.		
Sodium Chromate					1.	3.	
Strontium Chromate			2. H_2SO_4,Dil				
Zinc Bichromate		x			1.		
Cobaltous Bromide							
Cobaltous Fluoride		x					

(continued)

TABLE A-8 (continued).

Chemical	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
	Treatment Category						
Cobaltous Formate					1.		
Cobaltous Sulfamate		x					
Cupric Acetate						1.	2.Na_2S, Dil.
Cupric Aceto Arsenite	x						
Cupric Chloride						1.	2.Na_2S, Dil.
Cupric Formate						1.	2.Na_2S, Dil.
Cupric Glycinate						1.	2.Na_2S, Dil.
Cupric Lactate						1.	2.Na_2S, Dil.
Cupric Nitrate						1.	2.Na_2S, Dil.
Cupric Oxalate	x						
Cupric Subacetate			1.				2.Na_2S,Dil
Cupric Sulfate						1.	2.Na_2S, Dil.
Cupric Sulfate, ammoniated					1.		
Cupric Tartrate	x						
Cuprous Bromide	x						
Coumaphous	x						
Cresol	x						
Barium Cyanide				2. NaOH, Dil.		1.	
Calcium Cyanide				2. NaOH,Dil		1.	
Hydrogen Cyanide				2. NaOH,Dil		1.	
Potassium Cyanide				2. NaOH,Dil.		1.	
Sodium Cyanide				2. NaOH,Dil.		1.	2.Rinse $^{w/}$Ca(OH) strong
Cyanogen Chloride	x						
Cyclohexane	x						

(continued)

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
2,4-D(Acid)	x						
2,4-D(Ester)	x						
Dalapon	x						
DDT	x						
Diazinon	x						
Dicamba	x						
Dichlobenil	x						
Dichlone	x						
Dichlorvox	x						
Dieldrin	x						
Diethylamine			2. HCl,Dil.			1.	
Dimethylamine			2. HCl,Dil.			1.	
Dinitrobenzene	x						
Dinitrophenol	x						
Diquat	x						
Disulfoton	x						
Diuron	x						
Dodecylbenzene-Sulfonic Acid		x					
Doecylbenzene-Sulfonic Acid Calcium Salt		x					
Dodecylbenzene-Sulfonic Acid Isopropanolamine salts		x					
Dodecylbenzene-Sulfonic Acid Sodium Salt		x					

(continued)

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Dodecylbenzene-Sulfonic Acid Triethanolamine Salt		x					
Dursban	x						
Endrin	x						
Endosulfan	x						
Ethion	x						
Ethylbenzene	x						
Ethylene Diamine			2. HCl,Dil.			1.	
Aluminum Fluoride						1.	
Ammonium Bifluoride				2. $Ca(OH)_2$,Dil.		1.	
Ammonium Fluoride						1.	
Hydrofluoride Acid				2. $Ca(OH)_2$,Dil.		1.	
Sodium Bifluoride				2.$Ca(OH)_2$,Dil.		1.	
Sodium Fluoride				2.$Ca(OH)_2$,Dil.		1.	
Stannus Fluoride				2.Na_2CO_3 + $Ca(OH)_2$,Dil.	1.		
Formaldehyde						1.	
Formic Acid				2.$Ca(OH)_2$, Dil.		1.	
Fumaric Acid		x					
Furfural		x					
Guthion	x						
Heptachlor	x						
Hydrochloric Acid				2.$NaHCO_3$		1.	
Hydroxylamine	x						

(continued)

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Ferric Ammonium Citrate						1.	
Ferric Ammonium Oxalate						1.	
Ferric Chloride				2. $Ca(OH)_2$,Dil.		1.-3.	
Ferric Fluoride	x						
Ferric Nitrate				2. $Ca(OH)_2$,Dil.		1.	
Ferric Sulfate				2. $Ca(OH)_2$,Dil		1.	
Ferrous Ammonium Sulfate						1.	
Ferrous Chloride				2. $Ca(OH)_2$,Dil.		1.	
Ferrous Sulfate				2. $Ca(OH)_2$,Dil.		1.	
Isoprene	x						
Kelthane	x						
Kepone	x						
Lead Acetate					1.		
Lead Arsenate						1.	2. Na_2S,Dil.
Lead Chloride						1.	2. Na_2S,Dil.
Lead Fluoroborate		x					
Lead Fluoride						1.	2. Na_2S,Dil.
Lead Iodine						1.	
Lead Nitrate						1.	
Lead Stearate						1.	
Lead Sulfate					1.		
Lead Tetraacetate		x			1.		
Lead Thiocyanate		x					
Lead Thisulfate		x					
Lead Tungstate				2. NaOH,Dil.		1.	

(continued)

EPA-287 (Cin.)
(4-76)

TABLE A-8 (continued).

Chemical	Treatment Category Not treatable	Questionable	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Lindane	x						
Malathion	x						
Maleic Acid				2. $NaHCO_3$,Dil.		1.-3.	
Maleic Anhydride				2. $NaHCO_3$,Dil		1.-3.	
Mercuric Acetate					1.		
Mercuric Cyanide	x						
Mercuric Nitrate					1.		
Mercuric Sulfate		x					
Mercuric Thiocyanate	x						
Mercurous Nitrate			2. HNO_3,Dil.		3.	1.	
Methoxychlor	x						
Methyl Mercaptan					1.		
Methyl Methacrylate					1.		
Methyl Parathion	x						
Mevinphos	x						
Mirex	x						
Monoethylamine					1.		
Naled	x						
Naphthalene	x						
Napthenic Acid	x						
Nickel Ammonium Sulfate						1.	
Nickel Chloride						1.	
Nickel Formate						1.	
Nickel Hydroxide			2. HCl,Dil.			1.	
Nickel Nitrate						1.	

(continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
DROPPED HEAD BEGIN SECTIONS HERE
CENTER OF PAGE
TOP OF IMAGE AREA

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Nickel Sulfate						1.	
Nitric Acid				2. $Ca(OH)_2$,Dil. Na_2CO_3,Dil.		1.	
Nitrobenzene	x						
Nitrogen Dioxide				2. $NaHCO_3$,Dil.		1.	
Nitrophenol					1.		
Para-Formaldhyde					1.		
Parathion	x						
Pentachloro-Phenol	x						
Phenol				2. NaOH,Dil.		1.	
Phosgene	x						
Phosphoric Acid				2. NaOH,Dil.		1.	
Phosphorus	x						
Phosphorus Oxychloride				2. NaOH,Dil.		1.	
Phosphorus Pentasulfide				2. NaOH,Dil.		1.	
Phosphorus Trichloride				2. NaOH,Dil.		1.	
Polychlorinated-Biphenyls	x						
Potassium Hydroxide			2. HCl,Dil.			1.	
Potassium Permanganate				2. $NaHSO_3$,Dil.		1.	
Proponic Acid				2. Na_2CO_3,Dil.		1.	
Proponic Andydride				2. Na_2CO_3,Dil.		1.	
Propyl Alcohol						1.	
Pyrethrins	x						
Quinoline	x						
Resorcinol				2. NaOH,Dil.		1.	

(continued)

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

EPA-287 (Cin.)
(4-76)

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Selenium Oxide					1.		
Sodium Selenite					1.		
Sodium	x						
Sodium Bisulfate						1.	
Sodium Hydrosulfide						1.	
Sodium Hydoride			2. HCl,Dil.			1.	
Sodium Hypochlorite						1.	
Sodium Methylate						1.	
Sodium Nitrite						1.	
Sodium Phosphate (Dibasic)						1.	
Sodium Phosphate (Monobasic)						1.	
Sodium Phosphate (Tribasic)						1.	
Sodium Sulfide						1.	
Strychnine	x						
Styrene	x						
Sulfuric Acid				2. $Ca(OH)_2$,Dil. Na_2CO_3,Dil.		1.	
Sulfur Monochloride	x						
2,4,5-T (Acid)	x						
2,4,5-T	x						
TDE(DDD)	x						
Tetraethyl Lead	x						
Tetraethyl Pyrophosphate		x					
Toluene	x						
Toxaphene	x						

(continued)

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Trichlorfon					1.		
Trichloro-Phenol	x						
Triethylamine			2. HCl,Dil.			1.-3.	
Trimethylamine					1.		
Uranium Peroxide			2. HCl,Dil.		1.	3.	
Uranyl Acetate			2. HCl_3,Dil.		1.		
Uranyl Nitrate			2. HCl,Dil.		1.	3.	
Uranyl Sulfate			2. HCl,Dil.		1.	3.	
Vandium Pentoxide	x						
Vandyl Sulfate					1.		
Vinyl Acetate	x						
Xylene	x						
Xylenol		x					
Zectran	x						
Zinc Acetate					1.		
Zinc Ammonium Chloride					1.		
Zinc Borate		x					
Zinc Bromide						1.	
Zinc Carbonate			2. HCl,Dil.			1.	
Zinc Chloride						1.	
Zinc Fluoride			2. HCl,Dil.			1.	
Zinc Formate					1.		
Zinco Hydrosulfite		x					
Zinc Nitrate						1.	
Zinc Phenolsulfonate						1.	
Zinc Phosphide	x						

(continued)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.) (4-76)

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD BEGIN SECTIONS HERE

TABLE A-8 (continued).

Chemical	Treatment Category						
	Not treatable	Question-able	Weak acid	Weak base	Water rinse partial removal	Water rinse	Special treatment
Zinc Potassium-Chromate		x					
Zinc Silicofluoride						1.	
Zinc Sulfate						1.	
Zirconium Acetate		x					
Zirconium Potassium Fluoride		x					
Zirconium Nitrate						1.	
Zirconium Oxychloride						1.	
Zirconium Sulfate						1.	
Zirconium Tetrachloride						1.	

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

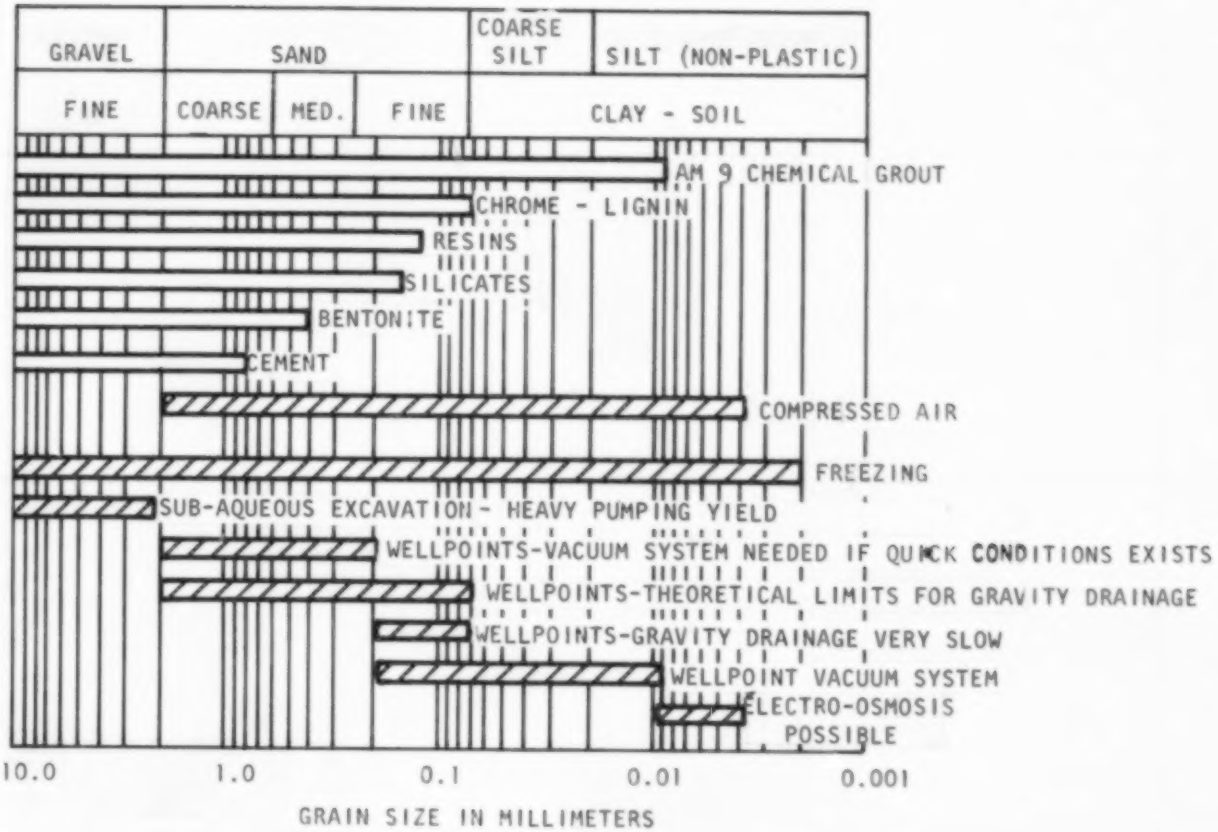


Figure A-1. Soil gradation limits for grout injection.
(from American Cyanamid Company)

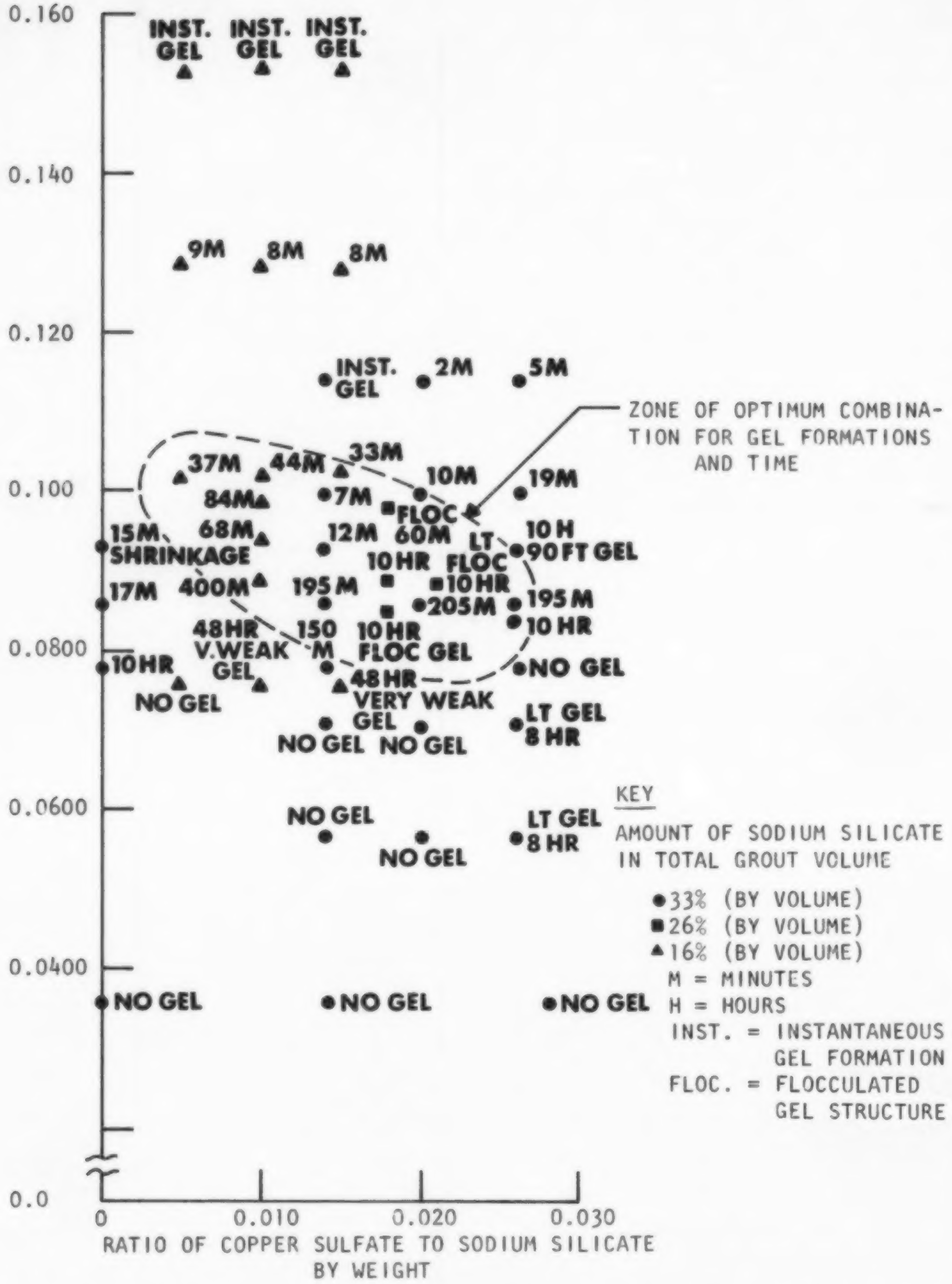


Figure A-2. Effect of various chemical combinations on the time of gel formation for silicate grout.

DEMONSTRATION OF IN-SITU EQUIPMENT

Site Location

The in-situ equipment demonstration was performed at Envirex Inc., Waukehsa, Wisconsin on December 1, 1978.

Grout Injectors

Four injectors were driven at 0.61m (2 ft) spacings into the fine sand soil. Five foot (1.5 m) lengths of non-perforated 1.9 cm (3/4 in.) heavy wall black pipe were used for injectors. Two sections were coupled to provide a 3.1 m (10 ft) total length for each injector driven. A loose fitting conical steel point was used as an injector tip. Driving was done using an air hammer with a special driving attachment fitting loosely over the top of the injector pipe.

Installation of the injectors went quite well, requiring a total driving time of about 40 minutes, or 10 minutes per injector. Driving times for each 1.5 m (5 ft) length varied somewhat depending upon the density of the soil. The fastest driving time for a 1.5 m (5 ft) section was approximately 40 seconds and the longest was 3 minutes. The soils encountered in the bottom portion of the injectors appeared to be loose or medium dense.

Prior to grouting, each injector was raised 5.1 cm (2 in.) to allow for adequate grout flow from the open end of the steel pipe. The injector spacing was selected to simulate a grout cutoff wall or envelope.

Injectors were installed vertically by standing on a 0.9 m (3 ft) high scaffolding. This was a suitable, versatile method.

Grout Mix

A bentonite/water mix was selected to simulate the pumping characteristics of a particulate grout, such as a cement/bentonite/water mix.

Calculations were made for the amount of grout required. They were based upon a cylindrical grouted volume, having a diameter 1.2 times the spacing between the grout injectors. It was assumed that grout would extend about 0.61 m (2 ft) below the injector tip, but that the upper 0.61 m (2 ft) of ground surface could not be grouted, and therefore the total grouted length for each injector was 3.1 m (10 ft). A porosity of 0.35 was selected as being representative of the fine sand soil to be grouted. This total volume of grout required for all four injectors was about 0.3 m^3 (80 gal).

Approximately 0.66 m^3 (175 gal) of water was placed in Tank No. 1, which was farthest from the bulk feed hopper, so that the conveyor system could be tested. A rather thick bentonite/water mix was selected for grouting. Two 22.7 Kg (50 lb) bags of powdered bentonite, by the trade name of Wel-Gel, were added to the hopper. Allowing for about 2.3 Kg (5 lb) of bentonite remaining in the hopper and the feed conveyor, the estimated consistency of the bentonite/water slurry was about 6.5 percent by weight.

Performance of the Conveyor System

The rotating spiral feed conveyor system worked quite well. It was noted that the hopper had to be sufficiently charged to provide enough material to fill the conveyor, but once this was accomplished, the flow in the conveyor seemed uniform and the introduction of bentonite into the mixing tank could be fairly well controlled.

Bentonite Slurry Mixing

After initial problems with the electrical fuse system, apparently due to the cold weather [ambient temperature was approximately 1°C to 2°C (34°F to 36°F) throughout the day], the mixer also worked well. It was noted that the bentonite which is added to the surface tends to remain on the surface and a sufficient length of mixing time is required to assure proper grout consistency. Also, because the fluid take-off is from the bottom of the tank, it is suggested that the operations manual indicate that the grout consistency be checked at the injector end, immediately prior to grout injection. This would be especially critical with chemical grouts.

Grouting Operations for a Single Injector

Grouting was initiated through Injector No. 1, using one of the four available Moyno pump systems. Figure A-3 indicates the position of the injectors and of the subsequent post grouting borings. Initially, the flow rate was in excess of 0.3 l/s (5 gpm) at pressures exceeding 1.4 Kg/cm^2 (20 psi) and a leak occurred at the ground surface within several minutes after the start of pumping. The flow rate was reduced to approximately 0.09 to 0.16 l/s (1.5 to 2.5 gpm) and the pressure maintained at between 1.1 to 1.3 Kg/cm^2 (15 to 18 psi) and the leak stopped. Grouting was continued in this fashion for about 15 minutes, at which time the injector was raised 51 cm (20 in.). Grouting was continued for another 15 minutes and the injector was raised an additional 23 cm (9 in.). Grouting through Injector No. 1 was performed for about 40 minutes, at various flow rates and pressures. The actual quantity of grout pumped was approximately 114 liters (30 gal) excluding the leakage noted at the ground surface.

Grouting from Two Injectors

Injectors No. 2 and 3 were grouted using the same Moyno pump, but with the dual injector setup. Separate lines extended from the machine to each of the injectors, rather than a single line with a "Y" or "T" connection at the location of the injectors. Each of the separate lines was monitored for pressure and flow rate.

During the dual injector grouting, significant variations in grout pressures and flow rates were noted. Injector No. 3, which was at a location which indicated the densest soil conditions during driving of the injector, consistently had the higher grout injection pressures. In some cases, up to 2.1 to 2.8 Kg/cm^2 (30 to 40 psi) was registered on gage. Injector No. 2 indicated only a 0.35 Kg/cm^2 (5 psi) pressure and a 0.09 to 0.13 lb (1.5 to 2 gpm) flow rate. The line valves were utilized frequently to control pumping from one injector or the other in order to observe flow rates and pressures. In general, pumping from a single injector or from both injectors did not seem to affect the performance of either injector in regard to its flow rate or pressure. Both Injectors No. 2 and 3 indicated leaks at the ground surface during the grouting operations, although they were smaller than for the first injector. These injectors were raised one time to about 76 cm (30 in.) above their starting level. Total grouting time for these two injectors was about 30 minutes. Calculations based upon the volume left in the mixing tank indicated that a total approximate volume of 64 liters (17 gal) of grout had been pumped through Injectors No. 2 and 3.

Performance of the Wilden Pumps

One of the Wilden pumos was tested by injecting water from Tank No. 2 through Injector No. 4. Pumping was initiated at a flow rate between 0.13 and 0.19 l/s (2 and 3 gpm) for a time of 10 minutes. No surface leakage was noted.

Effectiveness of the Grouting Operations

Three observational borings were performed after completion of the grouting operations (See Figure A-3). Boring B-2 was performed 30 cm (12 in.) east of Injector No. 1, boring B-3 was performed 23 cm (9 in.) west of Injector No. 1 and boring B-4 was performed at the location of Injector No. 3 after it was removed.

In general, the highest concentration of grout was found at the closest spacing to the center of the injector, as would be expected. Grout was found in at least the bottom 1.5 m (5 ft) section of Injector No. 3 (boring B-4). A 9 Kg (20 lb) bag sample was obtained of the grouted material for further laboratory testing. A standard split-barrel sample was obtained from a depth of 2.7 to 3.4 m (9 to 11 ft) at this location, which encountered grouted fine sand soil, similar to that noted on the auger flights. Of note was the fact that the soil strata changed and became much denser below a depth of 3.2 m (10.5 ft). This was indicated by the Standard Penetration Resistance Value, based upon the number of blows required to drive the split-barrel sampler. The grout did not apparently penetrate into this much denser zone below a depth of 3.2 m (10.5 ft).

The boring 23 cm (9 in.) west of Injector No. 1 (boring B-3) indicated the presence of grout more by the moist or wet condition of the soil than by the physical appearance which was prevalent at the location of Injector

No. 3. The grout appeared to extend to a depth of 3.6 m (11.8 ft) as indicated by the split-barrel samples which were obtained at depths of 2.0 to 2.4 m (6.5 to 8.0 ft), 2.6 to 3.1 m (8.5 to 10.0 ft) and 3.2 to 3.7 m (10.5 to 12.0 ft). Representative jar samples were obtained.

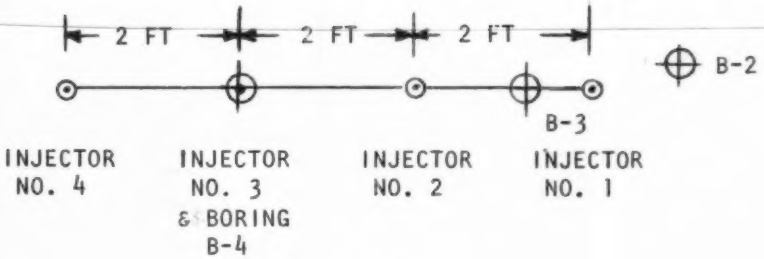
The presence of grout at the location 30 cm (12 in.) east of Injector No. 1 was much less obvious and, with the exception of a thin grout seam evident at a depth of about 3 m (10 ft), only a moisture increase in the soil could be construed as the presence of grout. Split-barrel samples were obtained at depths of 2.4 to 2.9 m (8.0 to 9.5 ft) and 3.1 to 3.5 m (10.0 to 11.5 ft).

It is not surprising that the presence of grout in this hole was minimal. The grout quantity was calculated to cover a volume extending to a 0.3 m (1.1 ft) radius about the injector hole. Hence, this boring was located at the outer circumference of this predetermined grouted volume.

Summary

In summary, it appeared that all mechanical systems functioned properly. Slight modifications to the electrical system and fusing of the mixer motors and heaters may be required. The injector driving system performed properly and within the amount of time typically expected for similar soil conditions. The conveyor system and grout mixing system worked well. Both the Moyno pump and Wilden pumps worked properly, including their associated monitor gages and flow meters. The flow totalizers may require calibration for the specific project on which they are utilized. The grouting operations seemed to work as expected, although several apparent shortcomings are evident. It will be difficult to grout the upper several feet at any location due to the lack of overburden pressure required to contain the grout before leakage would occur around the injector. Also, the ability to predict grout flow into the soil is difficult. These latter restrictions are a function of the inherent nature of a soil deposit and are not directly related to performance of the grouting equipment itself.

BEGIN FIRST
TYPING GUIDE SHEET
CENTER
TOP OF


2 FT
2 FT
2 FT
B-2
B-3
INJECTOR NO. 4
INJECTOR NO. 3 & BORING B-4
INJECTOR NO. 2
INJECTOR NO. 1

m = ft x 0.305

Figure A-3. Equipment demonstration - injector layout and soil boring location (December, 1978).

BEGIN LAST LINE OF TEXT
3/8''
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.)
(4-76)